AD NUMBER

AD081239

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational use; May 1955. Other requests shall be referred to Wright Air Development Center, Wright-Patterson Air Force Base, OH 45433.

AUTHORITY

AFWAL ltr, 17 Apr 1980

1

8/239

WADC TECHNICAL REPORT 55 154

FC

ACOUSTICAL ANALYSIS OF THE PROPOSED BIO-ACOUSTICS FACILITY, AERO MEDICAL LABORATORY WRIGHT-PATTERSON AIR FORCE BASE

JACK B. C. PURCELL

AND

THE STAFF OF BOLT BERANEK AND NEWMAN INC.

MAY 1955

WRIGHT AIR DEVELOPMENT CENTER

WADC TECHNICAL REPORT 55-154

ACOUSTICAL ANALYSIS OF THE PROPOSED BIO-ACOUSTICS FACILITY, AERO MEDICAL LABORATORY WRIGHT-PATTERSON AIR FORCE BASE

JACK B. C. PURCELL

AND

THE STAFF OF BOLT BERANEK AND NEWMAN INC.

MAY 1955

AERO MEDICAL LABORATORY
CONTRACT No. AF 33(616)-2151
PROJECT No. 7211

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
200 - 4 January 1956

F O R E W O R D

This report was prepared by the firm of Bolt Beranek and Newman Inc., under Contract No. AF 33(616)-2151, Call II, for the Wright Air Development Center, under authority of Project No. 7212 - 71708 entitled "Properties of Media for Vibratory Energy Transfer". Technical supervision of the preparation of this report was the responsibility of Major Horace O. Parrack, USAF, and Dr. Henning E. von Gierke, Aero-Medical Laboratory, Research Division, Wright Air Development Center, WPAFB, Ohio.

ABSTRACT

Analyses of the acoustical requirements for spaces in the proposed Bio-Acoustic Research Facility, Aero-Medical Laboratory, are presented. The analyses support the outline specifications and construction techniques proposed for this facility.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero-Medical Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

This report summarizes briefly the acoustical analysis and the recommendations for noise control for all the spaces comprising the Bio-Acoustics Research facility for the Aero Medical Laboratory at the Wright-Patterson Air Force Base, Dayton, Ohio. This report includes (a) a discussion of the establishment of the acoustical criteria for the various critical spaces, (b) the establishment of noise reduction requirements for all wall structures, (c) specification of wall structures, materials, room finishes and dimensions, and (d) general recommendations on the control of noise emanating from ventilating systems. In addition, an interpretation of the program requirements is presented upon which the acoustical analysis was based. Consideration has been given in this analysis not only to the laboratories of this facility but also to the administrative areas.

In the design of this facility, it has been necessary to establish some basic assumptions on the maximum exterior and interior noise levels as a function of frequency which will be generated in and around the building. These basic assumptions, coupled with the simultaneous use requirements and desired criteria in the critical test areas, have been used to establish the noise reduction requirements between the various separate areas. The simultaneous use requirements have resulted in a compact grouping of the test areas in order to permit functional operation of the facility as a self-contained entity. These requirements have necessarily introduced complexities in the basic structural design of the facility.

While many of the test areas similar to those proposed in this facility have been constructed in isolated cases, it is believed that this is the first attempt to consolidate all of these facilities into a single structure. It is hoped that the design requirements as set forth in this report will aid in the planning of administrative and technical facilities of future Air Force installations.

SECTION II

FUNCTION OF FACILITY

The primary function of the Bio-Acoustic Research Facility is to provide a suitable structure with the special equipment necessary to conduct a research and development program on the reduction and control of noise and vibration produced by operating Air Force equipment.

The facility has been planned for use in the performance of the following specific functions:

(1) To develop a system which will control human exposures to vibratory energy (noise and vibration) produced by operating Air Force equipment and facilities. Development of this system shall include provisions to perform all research and development necessary to reduce and control vibratory energy to the extent required:

- (a) to prevent human exposure to hazardous vibratory energy levels;
- (b) to prevent development of pathological states in exposed personnel;
- (c) to prevent producing hazardous physiological reactions among exposed personnel;
- (d) to maintain levels of vibratory energy which permit effective accomplishment of necessary functions during exposure;
- (e) to assure that vibratory energy levels are acceptable to personnel working or residing in proximity to USAF sources;
- (f) to maintain vibratory energy levels (produced by USAF operations, particularly flight operations) which are acceptable to residents of communities located adjacent to USAF Air Bases;
- (g) to insure that no damage occurs to the possession, both animal and real estate, of community residents.

(2) To develop equipment and techniques to control human exposure to high velocity hot gas jets produced by jet engines and rockets so that the following are achieved:

(a) personnel are protected from excessive heat;

(b) personnel are protected from blast effects;

(c) personnel are protected from noxious gases;

(d) control of vibratory energy is achieved to the maximum extent possible in conformance with the primary requirements.

(3) To develop criteria, based on data and information obtained from research and utilizing the capabilities of the equipment and procedures developed that will provide;

(a) guides for planning USAF operations and the location of operational facilities;

(b) guides to Air Base planning as related to noise and vibration problems;

(c) guides to estimating and evaluating community response to Air Force operations;

(d) methods for evaluating action taken to achieve noise and vibration control.

(4) To develop equipment and techniques to control vibratory energy produced by operating Air Force propulsive devices so as to prevent structural damage:

(a) to air frames and air frame components;

(b) to other structural elements located adjacent to operating aircraft or aircraft power plants.

Supporting functions of this research building are: (a) to provide facilities for calibrating acoustical measuring and recording equipment; (b) to assist those responsible for the development of power plants and the operation of power plant test facilities to provide the noise control measures necessary for personnel protection and for the

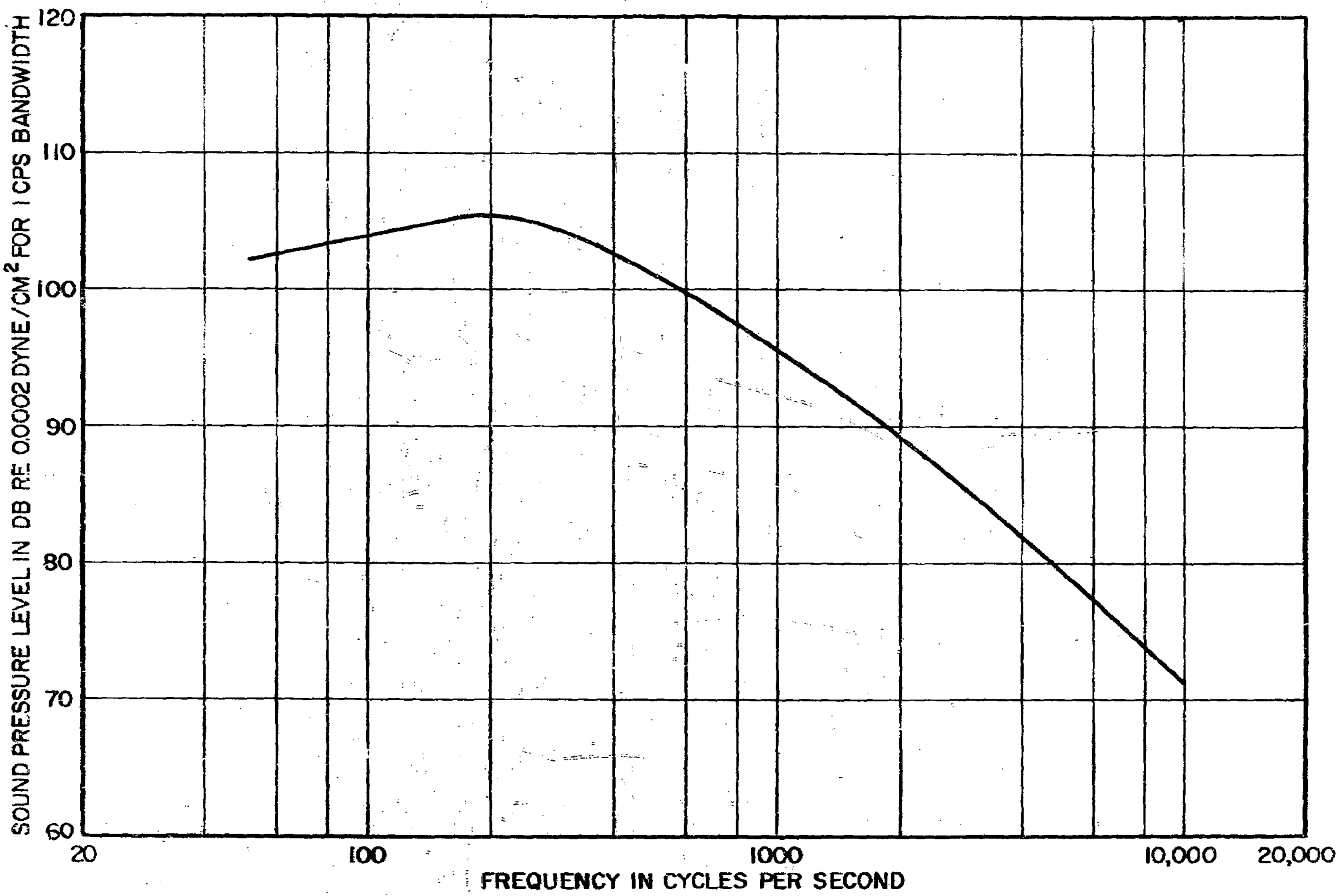


FIG. 1 ESTIMATED SPECTRUM LEVELS AT EXTERIOR WALL SURFACES OF ANECHOIC CHAMBER DUE TO B-52 FLYING 300 FT. OVERHEAD WITH ALL J-57 TURBOJET ENGINES OPERATING AT MILITARY POWER

protection of adjacent communities; (c) to assist various organizations of the Air Materiel Command in providing adequate noise control techniques and facilities for the protection of personnel in engine test cells, flight line maintenance operations and aircraft fabrication and repair facilities.

SECTION III

ACOUSTICAL ANALYSIS

The acoustical analysis of this facility has been performed with two primary objectives in mind:

(1) To provide for acceptable ambient sound pressure levels in various critical spaces;

(2) To provide special acoustic properties such as controlled reverberation, "free-field" conditions, diffuse sound field conditions etc. in various spaces.

The ambient noise levels in any room in the building will result from noise transmitted into the space from outside the building, or from adjoining rooms, or both. Another important contributor to the ambient noise levels will also be mechanical equipment. A detailed analysis of the mechanical equipment noise problem is not presented in this report and will be discussed only in general terms.

The maximum exterior noise source levels to be considered as governing the acoustical requirements for exterior wall isolation are assumed to be those produced by a B-52 aircraft flying over the facility at an altitude of approximately 300 ft. The B-52 is powered by eight J-57 turbojet engines without afterburner, each having a thrust of approximately 10,000 lbs. For this condition the estimated noise levels as a function of frequency existing over the exterior surfaces of the facility are plotted in Fig. 1 as spectrum levels in decibels re 0.0002 dyne/cm^2 for a 1 cps bandwidth. The equivalent octave band levels corresponding to these spectrum levels are also listed below in Table I.

TABLE I

ESTIMATED SOUND PRESSURE LEVELS AT EXTERIOR WALL SURFACES DUE TO B-52 FLYING 300 FT OVERHEAD WITH EIGHT J-57 TURBO-JET ENGINES OPERATING AT MILITARY POWER

Frequency Band cps	Sound Pressure Levels in decibels re 0.0002 dyne/cm^2
20-75	119
75-150	123
150-300	127
300-600	127
600-1200	125
1200-2400	122
2400-4800	117
4800-10000	113

The noise reduction requirements for the roof and wall surfaces of each of the spaces under consideration are determined by comparing the estimated maximum uncontrolled ambient noise levels in a room with the applicable criterion levels for the room. The differences in decibels as a function of frequency between the ambient levels and the criterion represent the noise reduction requirements. Since the intruding noise levels as well as the criteria differ from room to room, and also since several rooms have special acoustical requirements, the acoustical analysis of each room is discussed separately below.

A. Anechoic Chamber, Room 1-1

(1) Functional Requirements. The purpose of this space is to conduct research or development programs or test experimentation programs under conditions simulating free

space. Anticipated research programs will include hearing studies on man and animals, the calibration of microphones, the study of the acoustical properties of jet sound sources and the calibration and standardization of all special sound sources for generating very intense sound fields.

(2) Performance Requirements. Those requirements governing the acoustical performance of this room may be stated as follows:

(a) Sound pressure levels in the chamber will "range from 140 to 170 db higher".

(b) Outside noise transmitted into the chamber must be "non-detectable by the human ear".

(c) All interior room surfaces are to be non-sound reflecting or "anechoic".

(3) Criterion for Ambient Noise. The problem of establishing a criterion for ambient noise levels based upon a non-objective requirement that these levels be non-detectable by the human ear is a difficult one. First of all there is the problem of interpretation. In this respect it has been assumed that this requirement will be satisfied if the maximum ambient noise levels in the chamber lie in the neighborhood of the threshold of hearing for continuous noise for individuals with normal hearing. (The threshold for individuals who have acute hearing may be somewhat less.) Proceeding on the basis of this assumption one is then confronted with the fact that the threshold of audibility for continuous noise has not been measured. Therefore, the problem becomes one of utilizing available data relating to this problem to determine an acceptable engineering criterion.

Some of these data are summarized in Fig. 2. Curve 3 is a modified plot of the American Standards Association minimum audible field (MAF) absolute threshold curve for pure tones 1/. The measured threshold which was obtained from measurements on young subjects with acute hearing has been modified by taking into account the masking effect of critical bands of noise on pure tones to approximate the threshold for continuous noise. This modification took the form of subtracting from the pure tone threshold curve the critical bandwidth in decibels as a function of frequency.

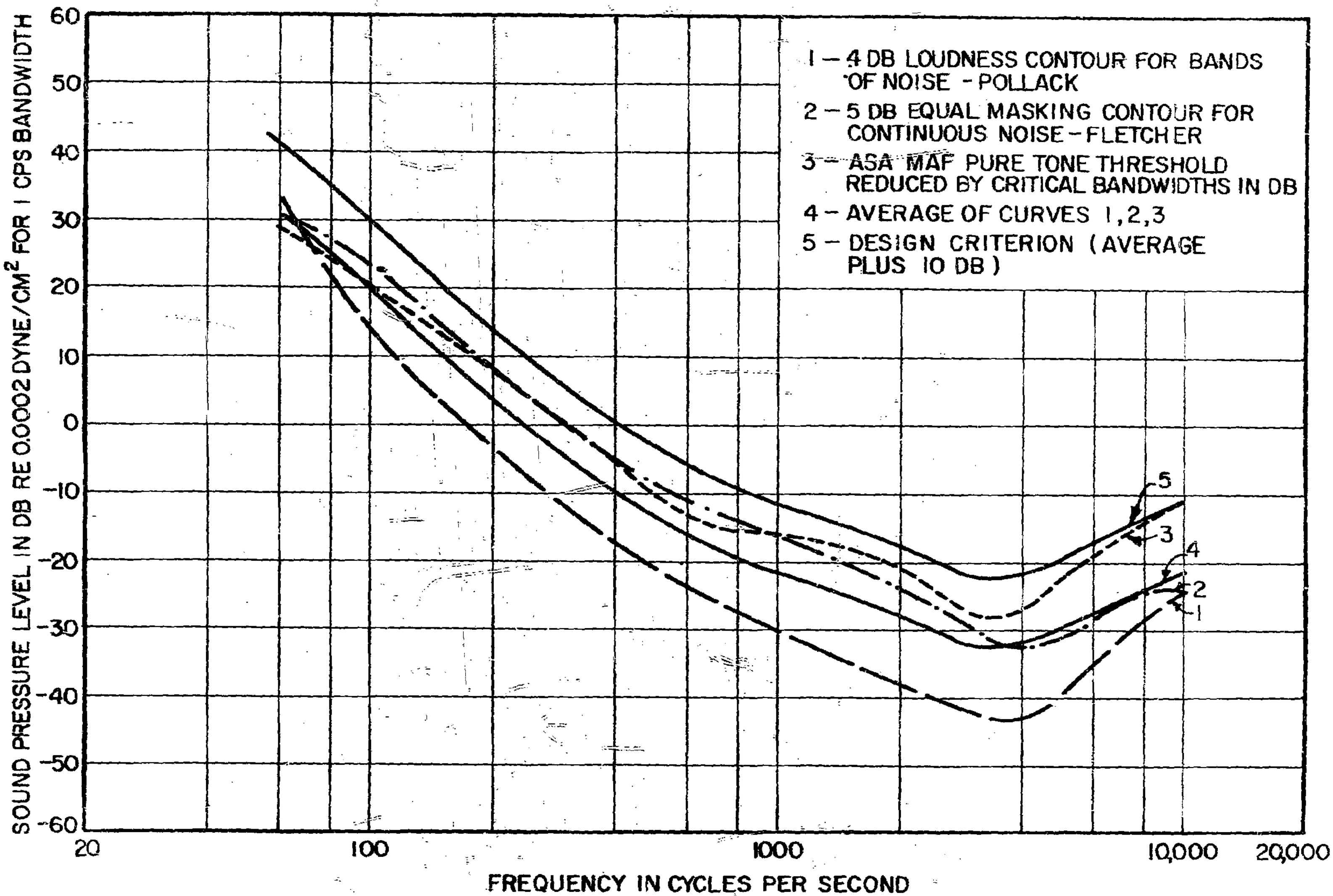


FIG. 2 DETERMINATION OF "NON-DETECTABLE" DESIGN CRITERION FOR AMBIENT NOISE LEVELS

Another approach is to utilize the equal loudness contours for bands of noise 250 to 300 mels wide as measured by Pollack 2/ on highly trained observers. The lowest equal loudness contour he reports is one for a loudness level of 4 db. Suitable corrections have been applied to the data, which were measured just beneath the cushion of an earphone, to convert them to MAF data. In addition, the data have been converted to spectrum levels (since the measurements are presented for bands of noise). The resulting spectrum is shown as Curve 1 in Fig. 2.

Still another possibility is to make use of the equal masking data of Fletcher and Munson 3/ which was presumably measured on subjects with acute hearing. They have published contours of equal masking for continuous noise. The lowest contour they report is one for 5 db masking. This contour has been plotted as Curve 2 in Fig. 2 and is directly comparable with Curves 1 and 3 since it also represents MAF data.

It is clear from an examination of Fig. 2 and the above discussion that there are several ways of estimating a suitable criterion applicable to this problem. Also, there is some uncertainty even among the data shown in Fig. 2 as evidenced by the ± 5 db or more spread of absolute levels among the three curves. Therefore, the selection of a criterion that will be completely satisfactory and at the same time economically practical can not be easily made. However, for engineering design purposes, the design criterion utilized in the analyses of this report is shown by the upper curve of Fig. 2, labeled "Design Criterion".

This design criterion curve was determined by first averaging Curves 1, 2 and 3 of Fig. 2. Since the data being utilized are either for people with acute hearing or for trained observers this average curve represents a lower bound. Therefore, to obtain a criterion of "non-detectability" applicable to individuals with normal hearing, the average curve has been raised by 10 db. This amount represents the average difference in normal threshold, as specified by the American Medical Association, and the threshold for well-trained listeners with acute hearing who were used in the determination of the MAP threshold in a laboratory.

(4) Free-Field Requirement. To satisfy the performance requirement of simulating the propagation of sound in a free-field condition, a special "anechoic wedge" construction has been shown on Fig. A-13. The design of this wedge has been based on the experimental data obtained by Beranek and Sleeper 4/. Individual wedges have been grouped into clusters

as shown for ease of construction and installation. A wedge cluster consists of nine separate wedges having 8 in. square bases. The total depth including the air space back of the wedge is 48 in. (from wall surface to tip of wedge). The air space is 4 5/8 in. behind the wedge, a base length of 7 3/8 in. for the wedge and a tapering length of 36 inches.

In Figure 3 the measured percentage of sound pressure reflection is plotted from a similar wedge construction 4/. The percentage sound pressure reflection is defined as one hundred times the ratio of reflected sound pressure to the incident sound pressure for sound normally incident on the structure. The selection of the percentage sound pressure reflection vs. percentage sound energy absorption is a more desirable ordinate since the region between 99 and 100 per cent energy absorption corresponds to 10 to 0 per cent pressure reflection respectively. Thus, using the percentage sound pressure reflection, one is able to obtain a more sensitive indication of the differences among the highly absorbent structures. It can be seen that the lower cut off frequency for this wedge construction is approximately 72 cps (the pressure reflection is greater than 10 per cent below this frequency, which represents a maximum drop of 20 db). The flow resistance specification for this wedge is approximately 10 rayls/in. This requirement is met by a 2.5 lb/ft3 density PF Fiberglas. It should be noted that the performance of these wedge structures is based on experimental data involving plane wave propagation in an 8 in. impedance tube. Under actual operating conditions of spherical wave propagation in the anechoic chamber, some variations will occur in the low frequency cut off, i.e., it may rise to 100 cps depending on the source and its location with respect to the boundary surfaces.

(5) <u>Noise Reduction Requirements</u>. The noise reduction requirements for the walls and roof of the anechoic chamber have been determined by subtracting the design criterion levels (see Fig. 2) from the maximum estimated exterior noise levels (see Fig. 1). These requirements have been plotted as a continuous function of frequency in Fig. 4 (Curve 1). It is seen that the required noise reduction is of the order of 60 db in the region of 50 cps and rises to a value greater than 100 db above 300-400 cps. This degree of reduction can only be achieved by a completely isolated double wall structure. The composite wall

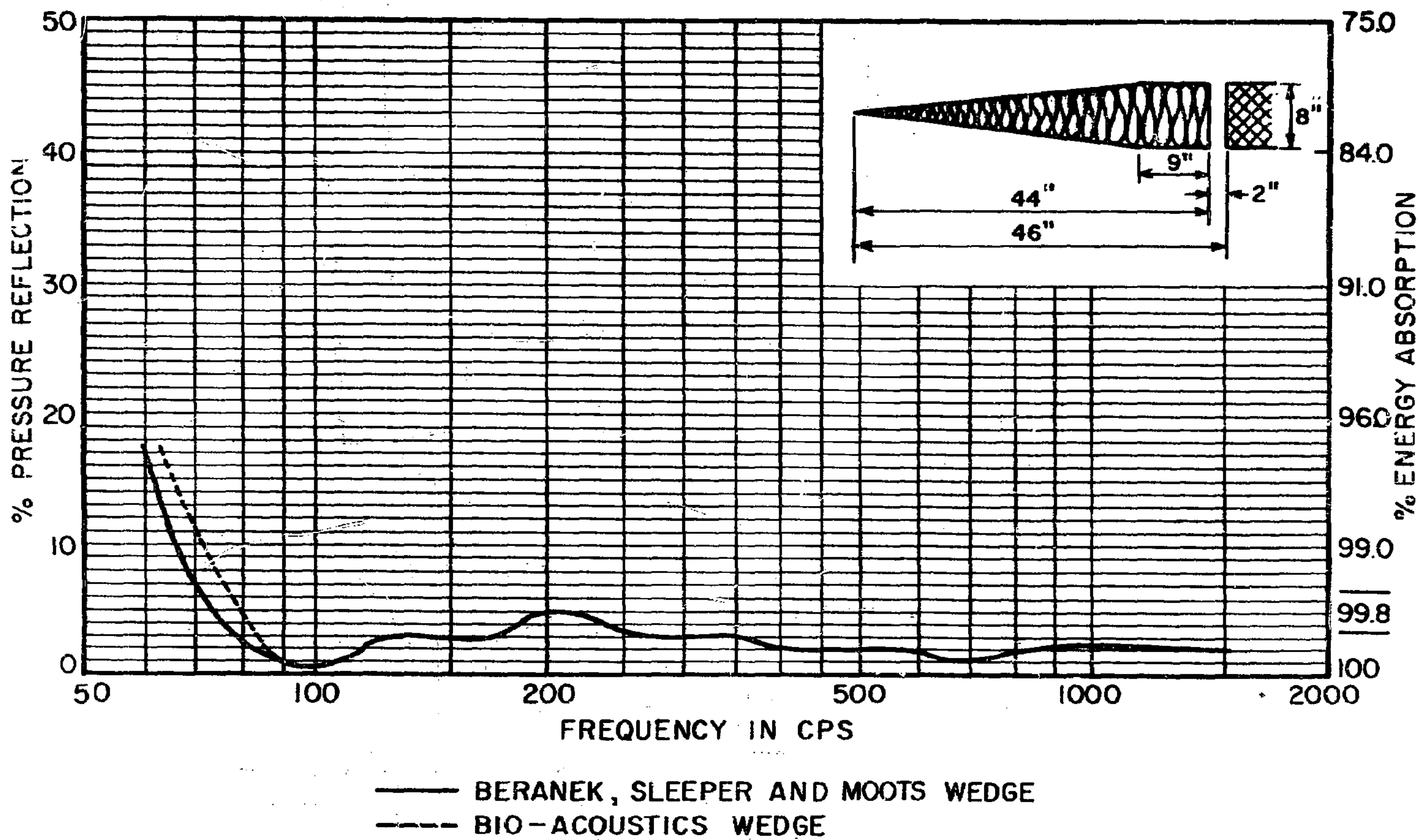


FIG. 3 SOUND REFLECTION CHARACTERISTIC-ANECHOIC WEDGE

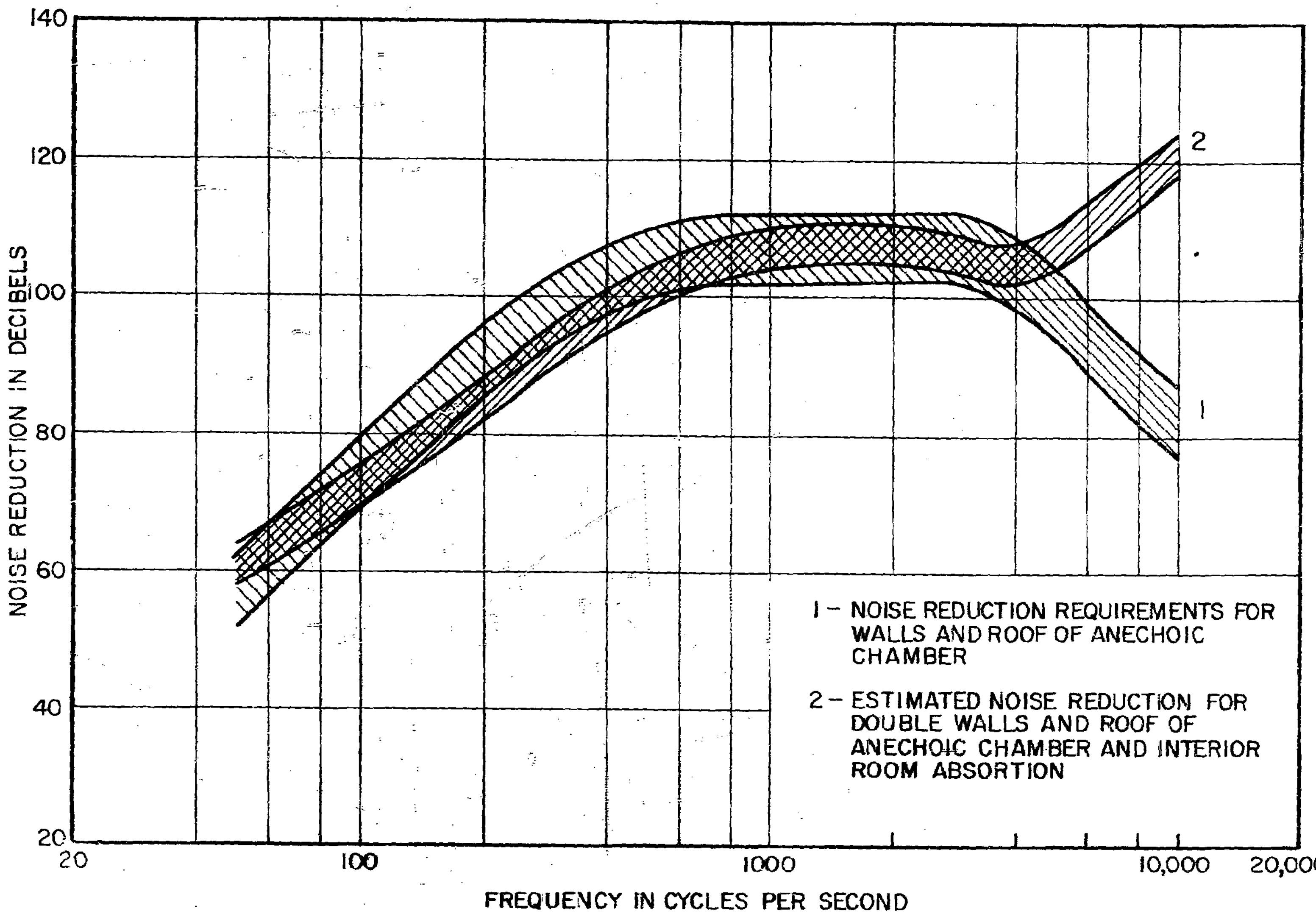


FIG. 4 COMPARISON OF NOISE REDUCTION REQUIREMENTS FOR ANECHOIC CHAMBER WITH ESTIMATED REDUCTION

construction selected for this design consists of two structurally independent 12 in. thick poured reinforced concrete walls, separated by a 4 in. cavity completely filled with a glass fiber blanket. Curve 2 of Fig. 4 is a plot of the estimated transmission loss of this double-wall structure plus some noise reduction realized from the sound absorption within the room. It can be seen that the requirements are just satisfied at frequencies below 4000 cps and exceeded at frequencies above 4000 cps. Figure 5 shows the estimated noise spectrum that would exist inside the anechoic chamber for the maximum expected exterior noise levels; i.e., when a B-52 is passing 300 ft overhead.

The above analysis is summarized in Table II below on an octave band basis. In Column 2 are listed the exterior noise levels (see Table I) due to the B-52 and in Column 3 are tabulated the criterion levels with a ± 5 db spread. Subtracting Column 3 from Column 2 results in the noise reduction requirements as listed in Column 4. The estimated transmission loss of the recommended double-wall construction is shown in Column 5. Column 6 shows the estimated reduction due to room sound absorption. The total noise reduction is a summation of Columns 5 and 6 and is listed in Column 7. It is seen that the requirements are met in all bands except the 150-300 cps band where the deficiency is only 1 db. In Column 8 is listed the estimated maximum ambient noise spectrum in octave bands.

It should be emphasized that these are maximum expected levels. Thus, if a jet aircraft powered by only one J-57 turbojet engine passes as close as 300 ft from the facility, maximum levels expected inside the chamber will be 9 db less than those shown in Fig. 5. For normal ambient levels outside the facility comparable to those near any airport or air base the interior levels will, of course, be even lower.

The transmission loss for the recommended double-wall construction for the anechoic chamber has been estimated in the following manner: At frequencies below the first resonance of the single cavity construction, it may be assumed that the single cavity wall behaves like a single wall of the same combined mass, i.e., the transmission loss in decibels can be determined from the well-known

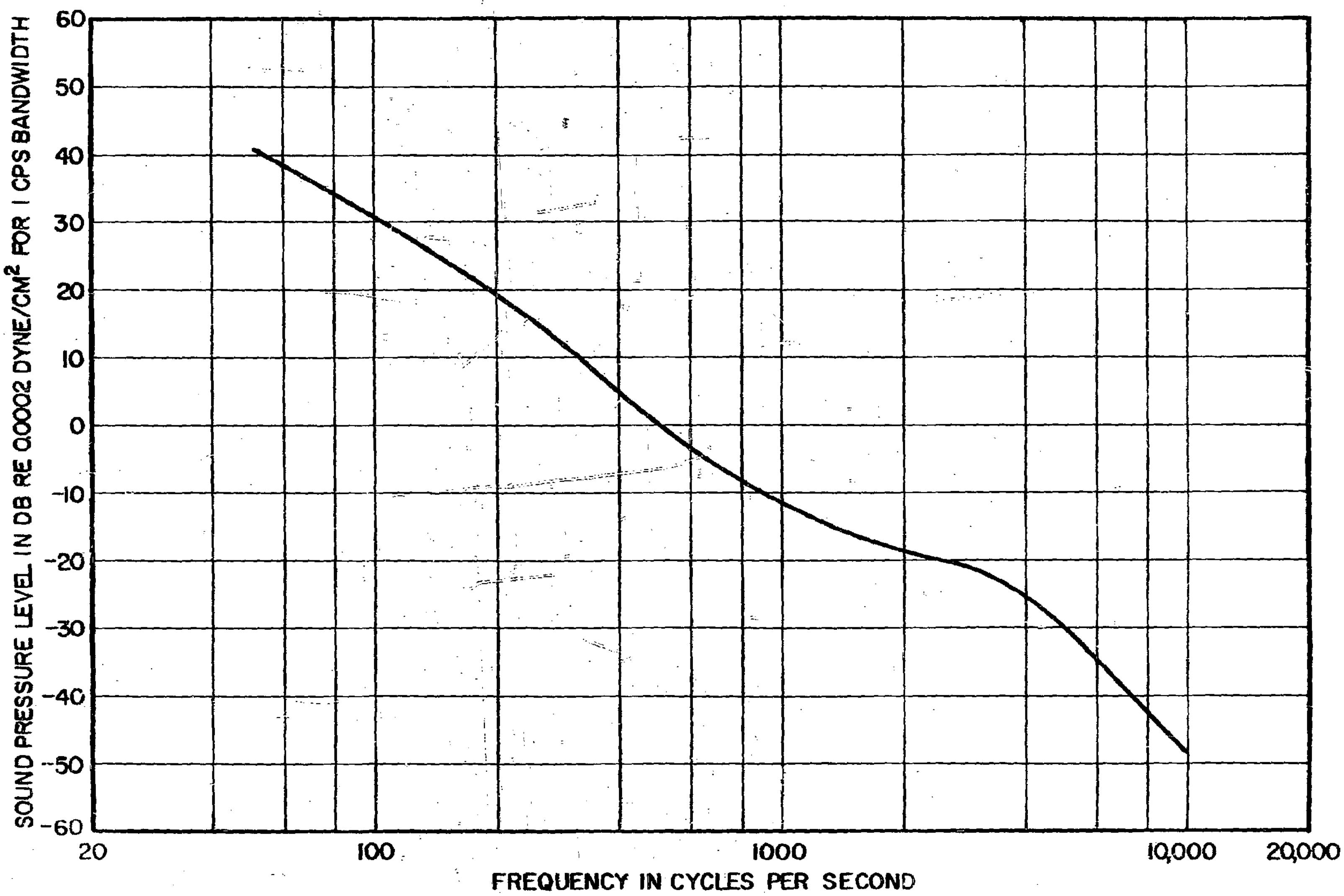


FIG. 5 ESTIMATED MAXIMUM AMBIENT NOISE LEVELS IN ANECHOIC CHAMBER

TABLE II

SUMMARY OF NOISE REDUCTION ANALYSIS FOR ANECHOIC CHAMBER

1 Frequency Band cps	2 Exterior Noise Levels (B-52) db	3 Design Criterion db	4 Noise Reduction Requirements db	5 Estimated T.L. of Double Wall db	6 Estimated Reduction Due to Room Absorption db	7 Total Noise Reduction db	8 Estimated Maximum Ambient Noise Spectrum in Anechoic Chamber db
20-75	119	62 ± 5	52-62	58	3	61	58
75-150	123	47 ± 5	71-81	71	3	74	49
150-300	127	35 ± 5	87-97	83	3	86	41
300-600	127	25 ± 5	97-107	95	4	99	28
600-1200	125	18 ± 5	102-112	102	4	106	19
1200-2400	122	15 ± 5	102-112	103	5	108	14
2400-4800	117	13 ± 5	99-109	100	5	105	12
4800-10000	113	22 ± 5	86-96	109	5	114	-1

random incidence mass law curve 5/. The approximate frequency at which the first resonance occurs in a single cavity construction is obtained from the following expression:

$$f_o = 50 \sqrt{\frac{m_1 + m_2}{m_1 m_2 d}}$$

where m_1 and m_2 are the surface weights of the respective walls in #/sq ft and d is the dimension of the cavity in ft.

For two 12 in. concrete walls spaced 4 in. apart f_o is approximately 10 cps. At this frequency the transmission loss is theoretically zero. However, in most practical cases the transmission loss decreases only slightly in the vicinity of resonance. In the frequency range above the first resonance, the transmission loss increases at a rate greater than the 5 to 6 db per octave expected for a single wall of an equivalent mass. For double wall structures it has been found that this increase is of the order of 12 db/octave up to the second wall resonance which occurs where the cavity dimension is equal to one-half wavelength in air. Above this second resonance which occurs at about 1600 cps, values of transmission loss increase at least 5 to 6 db/octave in accordance with the random incidence mass law for single walls.

Noise source levels in rooms adjoining the Anechoic Chamber, with the exception of a high intensity pure tone component produced by a siren in the Sound Sources Stage, are not expected to exceed the exterior noise levels estimated for the low-flying B-52. Consequently, the double-wall structure required for the roof and walls of the anechoic chamber will be more than adequate in providing noise isolation between adjoining rooms and the chamber. However, the simultaneous use requirement of the Sound Sources Stage (for experimental work in the coupled reverberation rooms) and the Anechoic Chamber will be difficult to satisfy if a siren is in operation in the Sound Sources Stage as a sound source for the coupled reverberation rooms due to back radiation of sound from the siren. This problem may be solved by scheduling of operations.

(6) Ventilating System. While the acoustic design for the ventilating system is not covered in detail in this report, it is nevertheless difficult to avoid considering it in the preliminary design stages. To minimize the possibility of additional noise sources contributing to the ambient levels in the chamber, a separate air conditioning unit system has been specified to supply and return air on a closed circuit for the chamber only. Sufficient space provisions have been made in the mechanical equipment penthouse for installing acoustical treatment required for the attenuation of expected noise levels from the fan and compressors of the air conditioning unit. Access panels should also be incorporated in the system for changing air filters in the ductwork. The specific acoustical design for this system cannot be made until final selection of the units has been made by the architect engineer.

It should be pointed out that the acoustical design of the ventilating system is very important in realizing the ambient levels as represented by the ambient noise design criterion (see Fig. 2). It is suggested, therefore, that plans be made to provide the architect with the services of acoustical consultants in arriving at the proper acoustical design for this system.

It has been established in the program that there will be experiments conducted which involve introduction of high velocity air streams into the Anechoic Chamber. The ductwork required for human comfort ventilating, shown in Figs. A-20 through A-22 is not capable of discharging these high velocities. Correspondingly, a specially designed system has been incorporated which exhausts to atmosphere. This system has been detailed on Fig. A-10. It will be capable of discharging the expected air volumes and will simultaneously provide the required sound attenuation necessary to satisfy the design criterion. When the high velocity air system is not in use, it is proposed that the opening be closed as shown in the detail labeled "Removable Kalamien Panel".

B. Studio - Room 0-3

(1) Functional Requirements. This area includes Rooms 0-3, 0-1 and 0-2 and will be used for conducting experiments on voice communication and the physiology of human speaking.

(2) Performance Requirements.

(a) Diffusion. To realize the optimum acoustical performance in a studio, particularly in regard to a non-discriminating monaural pickup, it is desirable that the room have a nearly equal distribution of sound pressure throughout its volume to provide a uniform transmission-frequency characteristic. Irregularity in the nodal patterns caused by standing and stationary waves (produced by outward and backward traveling waves which add in magnitude) is highly desirable. Particular attention should, therefore, be given to the room dimensions and gross shaping. Maximum randomization of the reflected sound energy, particularly in the speech bands, by the use of specially designed sound diffusing panels is mandatory.

(b) Reverberation. Variable reverberation characteristics are required to simulate many possible acoustical environments for experimental studies on speech articulation. Provisions should, therefore, be made for flexibility in placement and amount of sound absorptive material so that the results will not only yield variable reverberation, but additional diffusion. The basic room shall have no sound absorbing material so that maximum reverberation time may be realized.

(3) Criterion for Ambient Noise. To provide for ambient noise levels in the studio that will permit the satisfactory use of the studio as specified above, the same criterion employed in the Anechoic Chamber has been selected.

(4) Noise Control Analysis. The most critical exterior noise levels expected to be encountered during the operation of the studio are those shown plotted in Fig. 1 (and listed in Table I) due to a B-52 aircraft flying at approximately 300 ft altitude. Therefore, the noise reduction requirements for the exterior wall of the studio are similar for the

anechoic chamber and can only be satisfied by a double-wall construction. This construction consists of a 12 in. thick dense concrete exterior wall separated by a 4 in. cavity containing a glass wool blanket from a structurally isolated 8 in. dense concrete inner wall. The estimated values of transmission loss of this double-wall structure are slightly less than those for the double-wall structure recommended for the anechoic chamber. Nevertheless, this double-wall structure will be adequate because the exterior wall of the studio will be retaining earth for most of its height, thereby reducing somewhat the noise reduction requirements of the outer wall.

The double-wall structure, even if it retains earth for its complete height, prevents any possible "short circuiting" condition that would exist in the case of a single wall. With a single outer wall, airborne and structure borne vibrations could excite the exterior wall above grade and enter the studio by flanking through the foundation wall. The double-wall permits the studio to be completely isolated from this possible flanking path.

A double-wall construction has also been used for the interior walls, roof and floor of the studio. This structure consists of two 8 in. thick reinforced concrete leaves separated by a 4 in. space with a glass wool blanket filler. The sound isolating characteristics of this double-wall will provide a high degree of noise and impact isolation between the studio and adjoining spaces. The estimated values of transmission loss for this construction are listed in Column 2 of Table III. In Column 3 is tabulated the design criterion. Adding Columns 2 and 3 results in the maximum levels (Column 4) permissible in spaces adjoining the studio with the recommended double-wall structure. It is seen that the octave band noise levels are 109 db or higher in all bands.

(5) Special Acoustical Design.

(a) Frequency Transmission Characteristics and Diffusion. Ideally, optimum design of a studio would yield a maximum of sound diffusion so that there would be no sound pressure variation from point to point measured in the room volume at a given time.

TABLE III

MAXIMUM PERMISSIBLE LEVELS IN SPACES ADJOINING THE STUDIO WITH RECOMMENDED DOUBLE-WALL STRUCTURE FOR WALLS, ROOF AND FLOOR OF STUDIO

1 Frequency Band cps	2 Estimated T.L. of Two 8" Concrete Walls 4" Apart db	3 Design Criterion db	4 Maximum Permissible Levels in Adjoining Spaces db
20-75	54	62 ± 5	116 ± 5
75-150	67	47 ± 5	114 ± 5
150-300	79	35 ± 5	114 ± 5
300-600	91	25 ± 5	116 ± 5
600-1200	98	18 ± 5	116 ± 5
1200-2400	99	15 ± 5	114 ± 5
2400-4800	96	13 ± 5	109 ± 5
4800-10000	105	22 ± 5	127 ± 5

Practically, this is not possible. The variables which establish limits of diffusion as a function of frequency are:

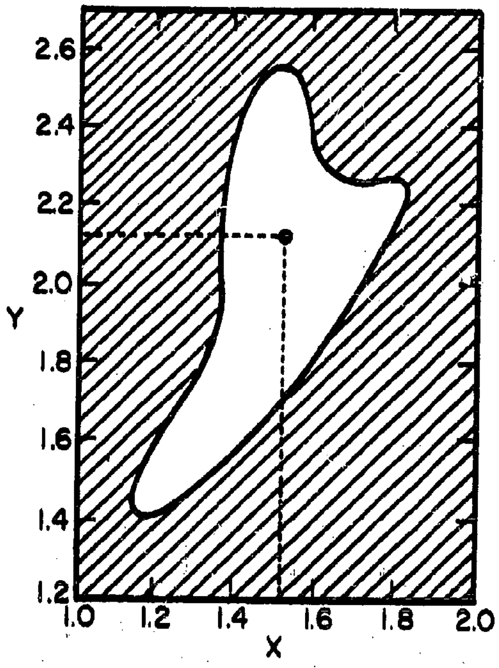
(1) Volume of room
(2) Dimension ratios
(3) Sound scattering elements introduced on the boundary surfaces and in the room volume
(4) Distribution of sound absorbing and sound reflecting materials which affect reverberation.

Special considerations have, therefore, been given to the studio dimensions in achieving the optimum frequency transmission characteristics at low frequencies. The dimensions of this room (20 ft x 28 ft x 13 ft) supply the dimensional ratios of 1 to 1.54 to 2.15. It may be seen from Fig. 6a, after Bolt 6/, that this falls within the area enclosed by the curve which represents the smoothest low frequency response (minimum degeneracies and maximum spacing between nodal planes). From Fig. 6b, for the room volume of 7,280 cu ft, it can be seen that the valid frequency range in which this response exists is - 30 cps to 90 cps.

To achieve the diffuse field conditions above the frequency ranges where dimensional ratios and gross shaping are predominant contributors, it is necessary to introduce sound scattering elements into the boundary surfaces. The effect of reflected wave propagation relative to the sound scattering elements may be briefly stated as follows:

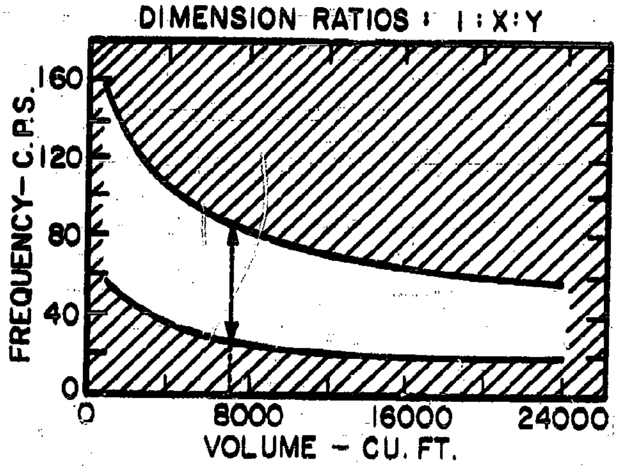
(1) If the dimensions of the scattering element are very much less than the wavelength, a minor effect on the wave front propagation will result.
(2) If the dimensions of the scattering element are comparable to the wavelength, a complex diffraction of the wave front will result.
(3) If the dimensions of the scattering element are much greater than the wavelength, the reflection of the wave front will be governed by the limiting case of geometrical optics.

Therefore, a series of specially designed trapezoidal concrete panels shown in Figs. A-14 and A-14A have been incorporated into the four walls and ceiling structure. The sound diffusing panels vary in horizontal and vertical dimension from 6 in. to 11 ft 6 in. in multiples of two, four and six inches, and vary in depth from 1 in. to 12 inches. These panels will furnish diffusion in the frequency range above 100 cps. The spacing irregularity of the panels and the irregular patterns of projection into the room will provide additional



CURVE ENCLOSES DIMENSION RATIOS GIVING SMOOTHEST FREQUENCY RESPONSE AT LOW FREQUENCIES IN SMALL RECTANGULAR ROOMS.

(A)



(B)

FIGURE 6

Room Proportion Criterion

diffusion in higher frequency ranges due to the edge effects of the panels. Additional high frequency diffusion is also achieved by the two-inch spacings between the separate panels and irregularities due to construction.

(b) Reverberation Control. Figure 7 shows two curves which represent the maximum and minimum reverberation times as a function of frequency attainable in the studio. This variable reverberation is achieved in the following manner: on the east wall of the studio a storage facility (detailed in Fig. A-14) has been provided for movable sound absorbing panels. These panels are 12 ft 0 in. high (floor to ceiling), 3 ft 0 in, wide, and 2 in. thick with a glass wool blanket filler faced with open wire mesh. A single door permits access to this space in the center of the east wall and a removable track section is then placed in the door to permit the panels to be rolled out into place. These panels are mounted on a single full swivel suspension from the overhead track. When all of the panels have been rolled from their storage position and set in place on the four walls, the resulting reverberation time as a function of frequency will be that indicated by the lower curve on Fig. 7. When the panels are in their stored position, the estimated resulting reverberation from the bare concrete room is represented by the upper curve in Fig. 7. It is evident, therefore, that the flexibility provided by these movable sound absorbing panels permits the achievement of any reverberation time shown within the boundary limits of the upper and lower curves of Fig. 7.

The reverberation characteristics of the studio have been calculated using the classical formula of Sabine with the Norris-Eyring correction and including air absorption in addition to the boundary absorption 7/. The equation is as follows:

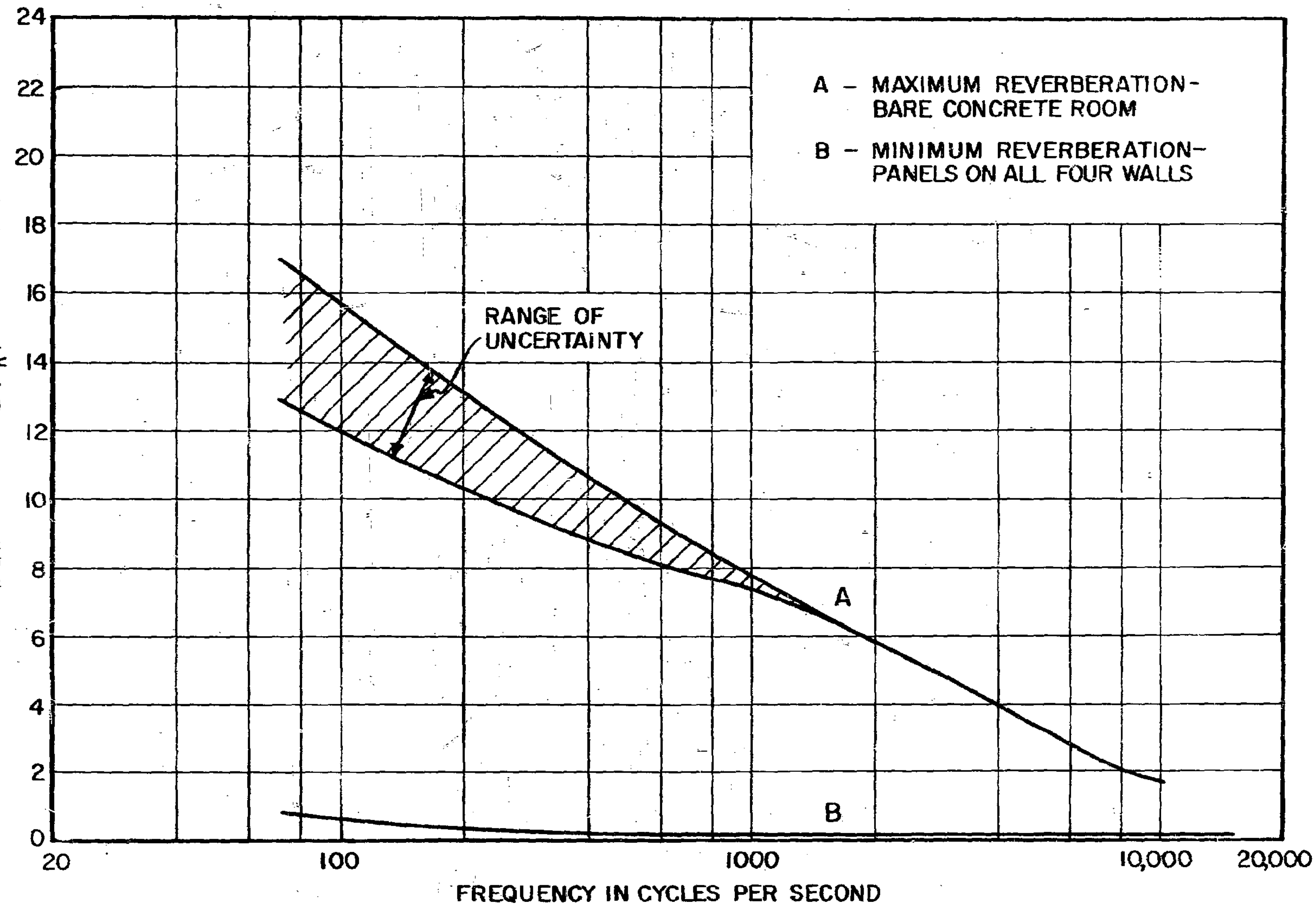


FIG. 7 ESTIMATED RANGE OF REVERBERATION TIMES FOR STUDIO, ROOM O-3

$$T_R = \frac{.049\ V}{S \log_e \left(\frac{1}{1-\bar{\alpha}}\right) + 4\ m\ V}$$

T_R = Reverberation time in seconds

V = Volume of room in ft^3

S = Area in ft^2

$\bar{\alpha}$ = Average absorption coefficient of the boundary surfaces at a particular frequency

m = Absorption coefficient of air at a specified relative humidity and frequency.

From the above expression one finds that the maximum reverberation time in the lower and middle frequency range (80 cps to 1000 cps) is limited by the hardness and non-porous characteristics of the boundary surfaces. Below 80 cps the reverberation time is not expected to continue to increase due to the viscous damping of structural vibrations. The reaction of the room to the very low frequencies is peculiar to the dimensions, shape and structure. The unique construction of the trapezoidal masses on the walls and ceiling, coupled with the structural isolation of the room from the building mass makes predictions in the very low frequency range virtually impossible within any degree of engineering accuracy. Above 1000 cps, the maximum reverberation time is primarily controlled by the air absorption. Values of air absorption used in the calculations discussed above are based on a relative humidity of 70 per cent, which is a practical design standard from the standpoint of human comfort and climate control.

(6) Ventilating System. To insure that the ambient noise design criterion levels will not be exceeded by ventilating noise, specially designed sound attenuating devices should be installed in the ventilating system servicing the supply and return air to the studio. Precautions should also be taken against sound originating in adjoining spaces and being

transmitted through the duct and the duct wall enroute and thence into the studio. Sound isolation will, therefore, be required between the duct system servicing the studio and potential sources of noise intrusion.

Preliminary design considerations have been given to the ventilating system servicing the studio. The special sound attenuating structures shown on the supply and return system in Fig. A-20 do not represent final design recommendations but are intended only to serve the purpose of indicating that some special sound attenuating structures will be required. It should be pointed out that the noise generated by the air handling units in this system will be the principal contributing factor to ambient sound pressure levels in the studio.

C. Sound Sources Stage and Associated Work Area (Rooms 1-25 and 0-24)

(1) Functional Requirements. This area will house noisy operations and machinery. It will be used to operate and to store the special sound generators (sirens, air jet generators and others) used with the anechoic chamber and the coupled reverberation rooms. Provisions shall be incorporated in the room design to permit noise generating equipment to be rolled into place at required openings into rooms 1-1 and 1-23. The sound source accessory area room 0-24 will be used to house air compressors, motor generators and compressed air storage tanks to be used for the special sound generators and other equipment.

(2) Performance Requirements. No specific acoustic performance requirements, for example, free field conditions, diffusion, etc. are required in the sound sources stage.

(3) During inactive and preparatory operation time of this space, a design criterion for speech communication of SC-45 has been selected 8/. This criterion is tabulated in Table IV. The number 45 refers to the speech interference level, which is the arithmetic average in decibels of the sound pressure levels in the three octave bands, 600-1200 cps, 1200-2400 cps, and 2400-4800 cps. In an SC-45 environment it is possible to carry on a relaxed conversation and communicate in a normal voice at 10 feet.

During operational periods where high intense sound fields will be generated while conducting an experiment, the back radiation of sound energy from the sirens or air jet streams will produce intense sound fields in the sound sources stage itself. Precautions should, therefore, be taken during operation of this space against personnel exposure to high intensity sound fields for prolonged periods.

TABLE IV

SC-45 DESIGN CRITERION FOR SOUND SOURCES STAGE

Frequency Band cps	Sound Pressure Level db
20-75	78
75-150	68
150-300	60
300-600	53
600-1200	48
1200-2400	44
2400-4800	42
4800-10000	41

(4) <u>Noise Control Analysis</u>. The acoustical requirements of noise isolation are concerned primarily with containing the high intensity noise levels generated in the sound sources stage itself. It has been assumed that the noise levels occurring in the exterior vicinity of the facility because of noise generated in the sound sources stage should not exceed an SC-50 criterion. These criterion levels are listed in Column 2 of Table V. The estimated transmission loss of the recommended double-wall construction is shown in Column 3. The double-wall consists of two separate leaves of 12 in. poured reinforced dense concrete separated by a 4 in. space completely filled with a glass wool blanket. In addition, the entire ceiling of the sound sources stage is to be covered with a 4 in. thick sound absorbing blanket of 4.25 lb/ft^3 density PF Fiberglas. This ceiling treatment will provide a reduction of noise levels

TABLE V

NOISE CONTROL ANALYSIS FOR EXTERIOR WALL OF SOUND SOURCES STAGE

1	2	3	4	5
Frequency Band	Design Criterion of SC-50 Outside Exterior Wall	Estimated T.L. of Recommended Double-Wall Construction	Noise Reduction Due to Room Absorption	Maximum Permissible Levels at Inside Face of Exterior Wall
cps	db	db	db	db
20-75	83	58	4	145
75-150	73	71	6	150
150-300	65	83	8	156
300-600	58	95	10	163
600-1200	53	102	11	166
1200-2400	49	103	12	164
2400-4800	47	100	13	160
4800-10000	46	109	13	168

as a function of frequency in the reverberant field as listed in Column 4 of Table V. Adding Columns 2, 3 and 4 results in the maximum permissible noise levels (Column 5) which can exist at the inside face of the exterior wall of sound sources stage if the noise levels outside the facility are not to exceed SC-50. It is seen that these maximum levels range from 145 to 168 db.

It is assumed that instruments for generating noise in the sound sources stage will produce pure tones having a sound pressure level of 140 to 170 db or higher. From a study of Table V, especially Column 5, it would seem that levels in excess of 168 db could not be generated without the risk of producing levels adjacent to the facility in excess of the design criterion. However, at these proposed high intensities the sound close to the source will undergo excessive attenuation due to the non-linear properties of the propagating medium (air). Therefore, although sources will be employed to generate levels of 140 to 170 db or higher, it is estimated that the levels just inside the exterior wall will not exceed those levels listed in Column 5 of Table V.

With the proposed double-wall construction the ambient noise levels in the sound sources stage due to the B-52 passing overhead will not exceed the design criterion of SC-45.

The high intensity sound produced in the sound sources stage will be directed either into the anechoic chamber or the coupled reverberation spaces. The instruments producing the sound will be sealed around their perimenter to the appropriate openings of the adjoining spaces. There will be some back radiation from these devices that is difficult to predict, and if occupancy is to be maintained during test operations, it may be desirable to give further study to enclosing these instruments to reduce the levels in the room itself.

The interior walls, roof, and floor of the sound sources stage are also of double-wall construction to provide a maximum degree of sound isolation for adjoining spaces during operation of the noise generating equipment in the sound sources stage. The estimated values of transmission loss for the recommended double-wall construction are the same as those listed in Column 5 of Table II on page 15. It is seen that the estimated transmission loss for this construction exceeds 70 db in the 75-150 cps and higher octave bands.

This conforms to a basis requirement that the transmission loss of the walls for this room be at least 70 db in the 75-150 cps, 150-300 cps and 300-600 cps octave bands, and higher at higher frequencies.

(5) Ventilating System. Inasmuch as the sound sources stage is the principal area for the generation of high intensity sound fields, the supply and return-air unit air conditioners that service the sound sources stage and air compressor space have been isolated from the mechanical equipment spaces which service the other rooms in this facility. It is felt that the additional expense involved in the design and construction of a special sound attenuating structure on the exterior wall is warranted by eliminating the possibility of sound transmission through a normal exposed duct system to the rooms requiring low ambient noise levels in the facility.

In the design of this special sound attenuating structure on the exterior wall, it has been assumed that the sound sources stage and air compressor space shall be used simultaneously. In the event that this is not always the case, the introduction of sound to either of the inoperative spaces when one is in operation should not present any further acoustical problems, providing the doors to both spaces are tightly closed.

(6) Equipment Openings. Figure A-17 indicates in detail the necessary provisions for sealing the required openings in the east and west wall of the sound sources stage. The removable panels which constitute the closure are constructed of sand-filled cellular steel or aluminum core with sheet steel facings bonded to the core. These panels are securely gasketed on their entire perimeter by means of a double gasket system of different rubber durometers, and pulled up tight by means of bolts on the panel frame. The use of small panels provides ease of handling and a variable opening size.

D. Coupled Reverberation Room Area (Rooms 1-23 and 1-24)

(1) Functional Requirements. The coupled reverberation rooms will be used for testing sound control structures for human and animal experiments requiring intense uniform sound fields and for evaluating the transmission loss of wall structures to be used in USAF facilities. Rooms 1-21 and 1-22 serve as control and recording equipment rooms and as a record analysis area.

(2) Performance Requirements. The acoustical performance requirements for the evaluation of transmission loss of walls require the use of two rooms and an intervening test panel opening. The locations of the sound source employed during transmission loss tests on wall panels will be either in the reverberation room 1-23 or in the wall opening to the sound sources stage. The test panel or the test wall is inserted in the 7 ft by 8 ft opening between the coupled reverberation spaces. The average sound pressure level is then measured in both rooms at a number of different positions. In room 1-23 the sound pressure level is measured in the reverberant region of the room.

In room 1-24 (the receiving room) the sound pressure level is either measured by averaging the sound pressure level over the entire volume of the room, or by averaging it in a plane parallel to and very near the test panel. To obtain, insofar as possible, a minimum deviation in the sound pressure levels in room 1-23, it is necessary that standing and stationary wave patterns be randomized by the introduction of non-parallel walls and diffusing panels. This is of particular importance in room 1-23 where the volume measurement technique will be employed to determine the average sound pressure level in the room. Developments in the experimental procedure for the evaluation of transmission loss of panels indicate that measuring the average sound pressure level in a plane parallel to and very near the test panel with considerable sound absorption in the receiving space (1-24) yields the best results 9/. Provisions should, therefore, be incorporated in room 1-24 for the introduction of sound absorbing panels when desired.

(3) Criterion for Ambient Noise. For proper use of these spaces it has been assumed that the ambient noise levels should not exceed the design criterion employed in the acoustical analysis of the anechoic chamber and the studio. These criterion levels are plotted in Fig. 2 and are tabulated in Column 3 of Table II on page 15.

(4) Noise Control Analysis. Since the ambient noise design criterion is the same as selected for the anechoic chamber and since the maximum exterior noise levels to be considered are those from the B-52, the noise reduction requirements for the exterior wall of the coupled reverberation area are those listed in Column 4 of Table II on page 15. The recommended double-wall construction of 12 in. of poured concrete, a 4 in. space filled with a glass fiber blanket, and 8 in. of poured concrete will adequately satisfy the requirements in all octave bands except the 150-300 cps band where the deficiency is only of the order of 3 to 5 db.

The design of the interior walls and roof of these spaces is based on two primary considerations: (1) the containment of high intensity levels in room 1-23, and (2) the need for reducing the noise levels transmitted from the sound sources stage to room 1-24 to the ambient noise criterion discussed above. The recommended double-wall constructions for these interior walls (combinations of two 8 in. walls spaced 4 in. apart, or a 12 in. wall spaced 4 in. away from an 8 in. wall, or two 12 in. walls spaced 4 in. apart, where the 4 in. space in each case is completely filled with a glass fiber blanket) will satisfy these requirements. These walls will, in general, provide the required transmission loss of 70 db in the 75-150 cps, 150-300 cps, 300-600 cps and higher values at higher frequencies.

The possibility exists that the simultaneous use of the anechoic chamber and coupled reverberation spaces may be somewhat limited when intense sound fields are being generated in the anechoic chamber, due to the back radiation from the noise generating equipment located in the sound sources stage.

(5) Reverberation Control and Diffusion. In room 1-23 (source room) the interior wall and ceiling surfaces are both highly sound reflecting and sound diffusing. A special metallic hardener admixture in the concrete finish will provide the walls and ceiling of the room with a low average sound absorption coefficient. The required diffusion is obtained by the use of specially designed panels shown in detail in Fig. A-18A

In the performance requirements above, it was pointed out that new measuring techniques may be employed in the receiving room for the measurement of transmission loss characteristics of wall panels. These techniques will not require a high degree of sound diffusion in the receiving room, but will require variable reverberation characteristics. In Fig. A-3 a series of movable sound absorbing panels are shown in a stored position on the west wall. These panels are to be rolled into place against the walls when measurements are to be taken requiring a non-reverberant room.

Since the walls of both rooms are non-parallel, no accurate prediction based on statistical data can be made relative to the low frequency response of each room. It is estimated, however, that adequate randomness will exist in the normal frequencies of the room. The possibility of flutter echoes has also been eliminated.

(6) Ventilating System. In order that the ambient noise design criterion selected for these spaces be satisfied, it is strongly recommended that provisions be made for the inclusion of specially designed sound attenuating devices in the supply and return air systems.

To prevent the entrance of sound into the duct system where the ducts penetrate spaces other than the reverberation rooms, for example, the hall, and the control and recording rooms, the entire ceiling below these ducts has been structurally detached from the duct work. This ceiling consists of a 1 in. thick hard finished plaster. Air Conditioning System No. 2 which supplies and returns air to the coupled reverberation rooms also serves, in addition to these spaces, the ear protection devices, the control and recording rooms, and the general physics laboratory. Typical sound attenuating structures have been shown in the diagrammatic air conditioning layout in Fig. A-21 to prevent the passage of sound to and from the ear protection devices test rooms and the physics laboratory into the duct work servicing the coupled reverberation spaces. The design layout shown in these drawings represents only a simple diagrammatic solution indicating the need for further study in this area.

E. General Physics Laboratory Area, Rooms 0-20-21-22-23

(1) Functional Requirements. This entire area will be used for general experiments in physical acoustics, for the test and evaluation of experimental equipment, and for high frequency equipment calibration.

It is also expected that high energy transient acoustical sources, such as explosions or shock tubes, will be used in these spaces.

(2) Performance Requirements. No specific requirements for acoustic performance is required in this room other than standard noise reduction treatment to provide a satisfactory acoustical environment. The adjoining rooms, 0-22, 0-23 and 0-21, that are to be used as experimental equipment control, testing and high frequency calibration, will be used as secondary testing areas for the general physics laboratory. Special provisions for instrument leads, test panels, and recording equipment shall be incorporated in the general physics laboratory for the purpose of recording

experimental work in the adjoining rooms. Special consideration should be given to the high frequency calibration space in order to obtain a nearly free-field condition in the frequency range above 5,000 cps.

(3) Criterion for Ambient Noise. The criterion for ambient noise levels in these spaces has been chosen as SC-35. This criterion will permit relaxed conversation at normal voice levels in all parts of the room. The sound pressure levels in octave bands for this criterion are listed in Table VI.

TABLE VI

SC-35 DESIGN CRITERION

Frequency Band cps	Sound Pressure Level db
20-75	68
75-150	58
150-300	50
300-600	43
600-1200	38
1200-2400	34
2400-4800	32
4800-10000	31

(4) Noise Control Analysis. The maximum anticipated exterior sound pressure levels to be encountered during normal operation of this facility will be those due to the B-52 as discussed in a previous section. These levels are plotted in Fig. 1 and listed in Table I on page 6. The estimated sound pressure levels in the adjoining air compressor space (on the west wall of the physics lab) are shown in Table VII. No valid prediction can be made at this time of the airborne noise to be generated in rooms 1-19 and 1-20 located directly above the physics laboratory. It is not expected, however, that these noise levels will exceed those in the air compressor space.

TABLE VII

AIR COMPRESSOR SPACE-ESTIMATED SOUND PRESSURE LEVELS

Frequency Band cps	Sound Pressure Level db
20-75	86
75-150	93
150-300	86
300-600	90
600-1200	90
1200-2400	90
2400-4800	90
4800-10000	87

The entire general physics laboratory has been placed below grade with double-wall construction. The structure provides more noise isolation from the exterior levels than is required to satisfy the SC-35 criterion. This selection was made to satisfy the requirement for a minimum transmission loss of 70 db (in the 75-150 cps, 150 to 300 cps, and 300-600 cps frequency bands, with greater attenuation in the frequencies above 600 cps) and to maintain constructional integrity with the double-wall structure specified for contiguous areas.

Sound absorption within rooms 0-20, 0-22, and 0-23 in the form of acoustic tile cemented directly to a suspended plaster ceiling has been recommended for control of noise originating in these areas.

The high frequency calibration space, room 0-21, has as an additional performance requirement, that of providing an essentially free-field boundary condition for frequencies in excess of 5000 cps. To achieve this condition, all boundary surfaces of the room, including the floor are finished with a 4 in. thick layer of 4 1/4 lb per cu ft PF type Fiberglas.

(5) Ventilating System. Special sound attenuating treatments should be provided in the ducts serving these spaces in order that the SC-35 design criterion is not exceeded.

Simultaneous use of the General Physics Laboratory and the high frequency calibration space should be avoided when explosive noise sources are used in the former.

The ventilating system for the high frequency calibration space requires special sound absorbing baffles in both the supply and return air ducts. A possible configuration for the duct work which permits the installation of required ductliner has been shown in Fig. A-20.

F. Noise Protective Equipment Design Area

(1) Functional Requirements. This area is located on the first floor and consists of rooms 1-19, 1-20, 1-21 and 1-22. It will be used for the design and testing of equipment to protect man from intense noise. Rooms 1-19 and 1-20 are the test areas, and rooms 1-21 and 1-22 are the control and recording rooms. Rooms 1-21 and 1-22 are also used in conjunction with the coupled reverberation rooms, 1-23 and 1-24.

(2) Performance Requirements. The varied operations that will occur in these test rooms require the need for two distinctly different acoustical environments. It is required, therefore, that two separate test facilities, one reverberant and the other non-reverberant, be provided for maximum flexibility under varying operating conditions.

(3) Criterion for Ambient Noise. In order to provide maximum latitude for performing tests in rooms 1-19 and 1-20, the ambient sound pressure levels should not exceed the "non-detectable" design criterion shown in Fig. 2. The SC-35 criterion listed in Table VI on page 34 was chosen as a design criterion for rooms 1-21 and 1-22. This criterion provides a suitably low ambient noise level for personnel operating the recording and measurement equipment.

(4) Noise Control Analysis. The estimated maximum exterior sound pressure levels and the interior ambient noise level criterion for this space are the same as described in the noise control analysis for the anechoic chamber. The determination of the wall requirements for these rooms follows

that for the anechoic chamber. The recommended exterior double-wall structure for this space consists of an 8 in. thick poured concrete wall, a 4 in. air space with glass wool filler, and a 12 in. exterior wall of poured concrete. This structure will satisfy the design criterion for rooms 1-19 and 1-20 in all bands except the 150 to 300 cps band (where the deficiency is only of the order of 3 db).

For achieving the SC-35 criterion in the control and recording rooms 1-21 and 1-22, it has been necessary to continue the double-wall construction to the interior walls for the purpose of "containing" the noise within the ear protection test facilities. This double construction has been utilized in the floor of both test spaces for containing and excluding noise to and from the physics laboratory and high frequency calibration spaces directly below.

A double-wall structure was not recommended for the exterior wall of room 1-22 because it was felt that the occasional passage of a B-52 would not hinder operations in rooms 1-22 and 1-21 since the SC-35 criterion would be exceeded only for very short periods of time.

The separate requirements of reverberant and non-reverberant conditions call for two separate test spaces with appropriate interior finishes to provide the desired reverberation characteristics. The interior finish of room 1-19 consists of exposed concrete for the four walls and the floor, and a suspended 1 in. thick hard plaster ceiling.

A non-reverberant condition is achieved in room 1-20 by an interior finish of a 4 in. thick sound absorbing blanket of 4 1/4 lb/ft^3 PF Fiberglas applied to the walls and to the 1 in. thick plaster suspended ceiling. The floor is covered by rubber tile.

(5) Ventilation System. Particular attention should be given to the design of adequate sound attenuating treatment in the ventilating ducts serving these rooms.

In Fig. A-21 a possible configuration is shown for achieving the desired noise reduction between the ear protection test spaces during simultaneous use. This system consists of two specially designed baffle arrangements in the supply and return systems providing a maximum run of duct within practical limitations for incorporating sound absorbing lining. Special design features have also been incorporated by the introduction of the separate baffle systems for achieving the desired attenuation between the coupled reverberation spaces and the control and recording rooms for the ear protection test spaces. It should be noted that the baffle arrangement shown in the ceiling of the janitor's closet, room 1-18, is a two-layered system so that the supply and return operate from completely independent baffled arrangements. Further study should be given to a more detailed analysis of the specific acoustical requirements for this duct work.

G. Audiometry Area

(1) Functional Requirements. This area is located on the basement floor and includes rooms 0-6, 0-7, 0-9 and 0-10. It will be used for research on human hearing and the effect of noise on the ear and the hearing mechanism.

(2) Performance Requirements. No special design considerations (with the exception of the composite double floated construction) such as room shaping and special sound absorbing finishes are required for these spaces.

(3) Criterion for Ambient Noise. The precision measurement technique used in clinical audiometry dictates the selection of an ambient noise criterion for rooms 0-6, 0-7 and 0-9 equal to the "non-detectable" design criterion shown in Fig. 2 and tabulated in octave bands in Column 3 of Table II on page 15.

In room 0-10 the ambient noise requirement is not as stringent as in rooms 0-6, 0-7 and 0-9. To provide a suitably low background noise environment for personnel operating recording and measurement equipment in this space, a design criterion of SC-35 has been selected. This criterion is listed in octave bands in Table VI on page 34.

(4) Noise Control Analysis. The noise reduction requirements for the exterior wall of room 0-6 will be approximately the same as those listed in Column 4 of Table II on page 15 since the design criterion and the maximum exterior levels are the same as considered in that analysis. The recommended double-wall construction of 12 in. of poured concrete, a 4 in. space filled with a glass fiber blanket, and 8 in. of poured concrete will adequately satisfy the requirements in all octave bands except the 150-300 cps band where the deficiency is only of the order of 3 to 5 db.

The transmission loss of the recommended exterior wall will, in general, satisfy the requirement of a 70 db wall as described in previous sections. This requirement also dictates the choice of a double-wall construction for the interior walls of rooms 0-6, 0-7 and 0-9.

The exterior wall of the Audiometric Records room, 0-10, has been recommended to be of single construction of 12 in. of poured concrete. This wall will provide adequate isolation from normal exterior noise levels to satisfy the design criterion for this space of SC-35. During the occasional passage of a B-52 300 ft overhead the noise levels in this space will exceed the SC-35 criterion levels. However, it is felt that these transient increases in noise level will not hinder operations in this space and consequently do not warrant a double-wall construction.

To reduce, as much as possible, structure-borne vibrations and impact noises caused by footfalls in the office areas above the audiometric testing area, we have recommended that the ceiling of the separate test spaces be lowered by a clear distance of 4 ft. The additional space which this measure provides permits ease of access to duct runs for supply and return air required for the rooms. A suspended plaster ceiling 1 in. thick has been recommended for the entire audiometric record space to reduce the transmission of sound from this area into the duct work enroute and thence into the test spaces through the register openings.

Although the performance requirements for these spaces as described above do not specify any need for individual room shaping or diffusion, etc., it is recommended that the walls and ceiling of each of the test areas be finished in a 1 in. thick standard perforated acoustic tile to provide general noise reduction.

(5) Ventilation System. In Fig. A-20a possible configuration of ventilation duct work is shown that provides a maximum run with a minimum of three 90-degree bands for the incorporation of sufficient sound absorbing treatment to satisfy the design criteria in these spaces. Special consideration should be given to acoustical treatment in the ducts that join test rooms to prevent "short circuiting".

H. Administrative Laboratory and Control Areas

(1) Performance Requirements. Although the acoustical performance requirements of the laboratory, administrative, and control areas are not as stringent and as complex as the test areas, some attention has been given to their separate acoustical environments. A discussion of the design requirements follows:

(a) Exterior Walls. It was established during the initial phase of planning that a sound transmission loss of 45 db in the frequency bands of 75-150 cps, 150-300 cps, and 300-600 cps would be adequate for all exterior walls. From the random incidence mass law, it was determined that a wall having a mass of 140 #/sq ft would be required to meet this criterion. The most economical method for achieving this mass is a poured reinforced concrete wall having a thickness of 12 in.

It was further established that any penetrations of the exterior wall for fenestration purposes would be undesirable since the resulting decrease in the required mass per unit area would materially reduce its sound isolating properties.

(b) Interior Walls. A structural design employing a conventional column and beam construction is not easily adapted to the unique acoustical requirements of this facility. For this reason, an integrated wall bearing structural system has been designed which not only satisfy the complex requirements of double-wall construction and tiers of floated rooms (for the test area) but also will be economically practicable and acoustically adequate for noise isolation.

A transmission loss of 40 db is required for walls between adjoining rooms in the non-critical areas to assure adequate privacy. In order to meet this criterion in the 75-150 cps band, as previously discussed, the wall must have a surface weight of approximately 95 lb/sq ft. The most economical construction for achieving this mass is an 8 in. thick poured reinforced concrete. This wall construction has been used throughout the administrative and laboratory areas of the facility.

The use of movable partitions for laboratory and office areas, while permitting some flexibility in the use of space, would introduce some serious sound isolation problems between adjoining rooms. The degree of flexibility of these partitions depends upon their lightweight panel construction for ease in erection and dismantling. Since the effective isolation of sound in air is achieved by massive, impervious single or multiple construction, it can be seen that air leaks through joints at panel intersections combined with their lightweight render this type of construction unsuitable in this facility. Investigation of several prefabricated movable partitions indicated that a deficiency of 15 to 20 db existed in the transmission loss requirements as specified.

(c) Floors. The transmission loss between adjoining rooms of 40 db in the critical frequency range described under the interior wall requirements is also applicable to adjoining rooms located one above another. To meet this requirement, the first floor construction must have a surface weight equivalent to that of the interior walls (95 lb/sq ft). In addition to the requirements of airborne noise isolation, precautions have been taken to reduce the impact transmission caused by footfall and rolling stock from the free-field measuring deck to the first floor and from the first floor to the basement level. Since bare concrete has an impact transmission approaching unity (zero transmission loss), a resilient pad of glass fiber 1 in. thick has been sandwiched in the first floor floor construction as a decoupling system.

Floor construction in the non-critical test areas consists of a 6 in. structural concrete slab and a 2 in. floated concrete slot separated by the resilient pad.

A similar construction has been employed in the free-field measuring deck to satisfy airborne sound isolation requirements and impact transmission to first floor areas.

(2) Criterion for Ambient Noise. To provide for ambient noise levels in the non-critical test areas that will permit the satisfactory use of telephone, and relaxed conversation at distances up to 10 ft, a design criterion of SC-45 has been selected. This criterion is tabulated in Table IV on page 27.

(3) Ventilating System. During normal operation of this facility, when the estimated exterior noise levels are not in excess of SC-50, the ventilating system will be the principal noise contribution in the non-critical areas. Provisions should therefore be made in the duct work from the point of takeoff of the fan to incorporate the necessary sound attenuating treatment to meet the SC-45 criterion. Duct layouts between adjoining and more remote areas served by the same system should provide space for sound absorbing lining and additional bends as required to reduce the possibility of room to room transmission. A possible configuration for the duct work servicing the two floors is shown on Figs. A-20 through A-22.

(4) Doors. In Fig. A-16, two alternate methods are shown for achieving an airtight closure on doors in non-critical test areas. The requirements for sound isolation do not justify the use of special "soundproof" doors in these rooms.

APPENDIX I

COST ESTIMATE OF ACOUSTICAL TREATMENT

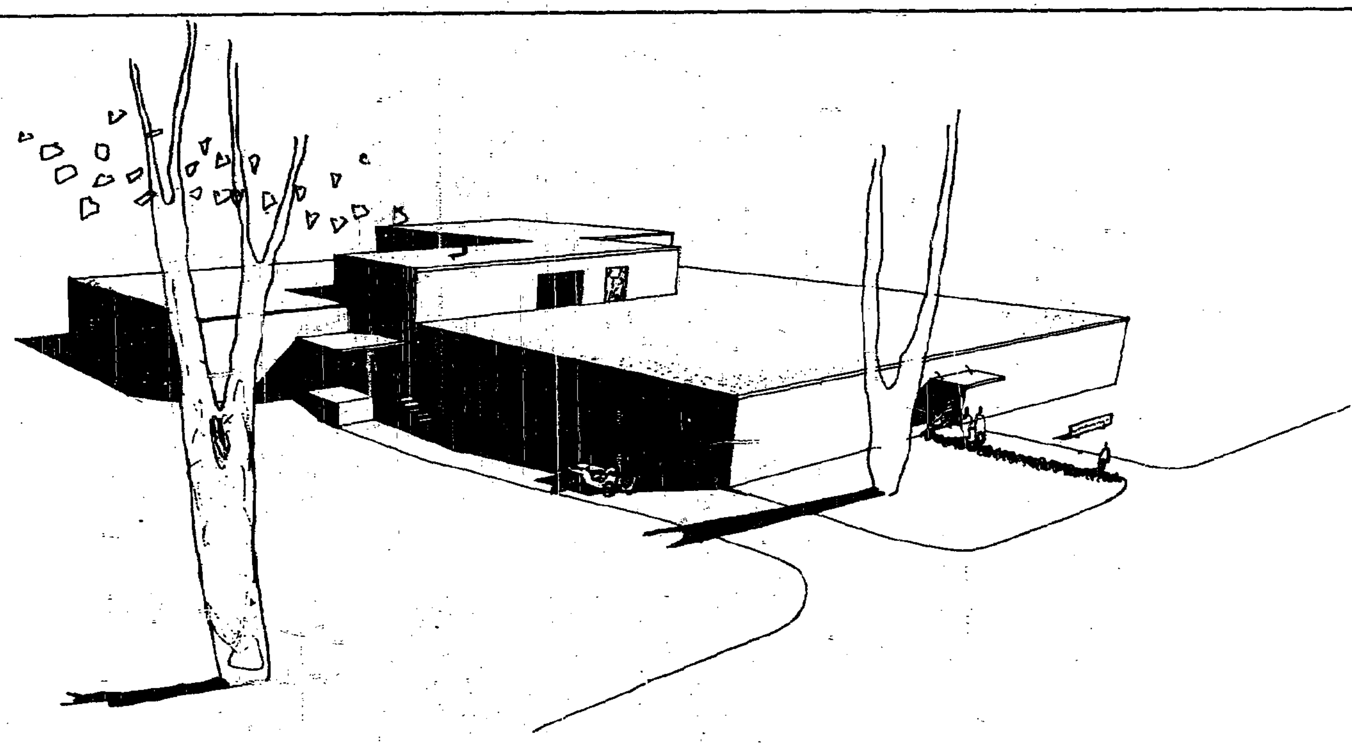
The following represents a best estimate of the cost of various acoustical treatments required for the proposed research facility. The figures were obtained through conferences with various acoustical materials manufacturers and acoustical contractors. The figures include cost of material, installation, and fabrication and shipment of any special units such as anechoic wedges and sound absorbing panels from a point of fabrication such as Cambridge, Massachusetts to Dayton, Ohio.

Load-bearing glass fiber material in double floor construction	$42,000
Non-load-bearing glass fiber material in double-wall and ceiling construction	10,000
Glass fiber material in resilient floor construction	4,500
Anechoic Room treatment including stretched cable floor	60,000
Special air intake and exhaust systems for Anechoic Room (1-1) and Rooms (0-24 and 1-25)	2,000
Glass fiber sound absorbing treatment ...	5,500
Standard acoustical tile sound absorbing treatment	5,000
TOTAL	$128,500

It should be noted that costs of acoustical treatment for the Heating Ventilating and Air Conditioning System (with the exception of the special air intake and exhaust systems for the Anechoic Room and Rooms (0-24) and (1-25)) and the various mechanical systems are not included in the above estimate. Until the above systems are designed, it is difficult to predict the extent of the acoustic treatment required and hence the cost of such treatment.

The series of figures presented in this appendix are reproductions of the drawings originally submitted with the acoustical recommendations for the Bio-Acoustic Research Facility.

The reproduction of the original drawings has been done on a reduced scale. Therefore, the indicated dimensions should be employed, and the figures should not be scaled.



RESEARCH FACILITY — AERO MEDICAL LABORATORY — BIO ACOUSTICS

FIGURE A-1

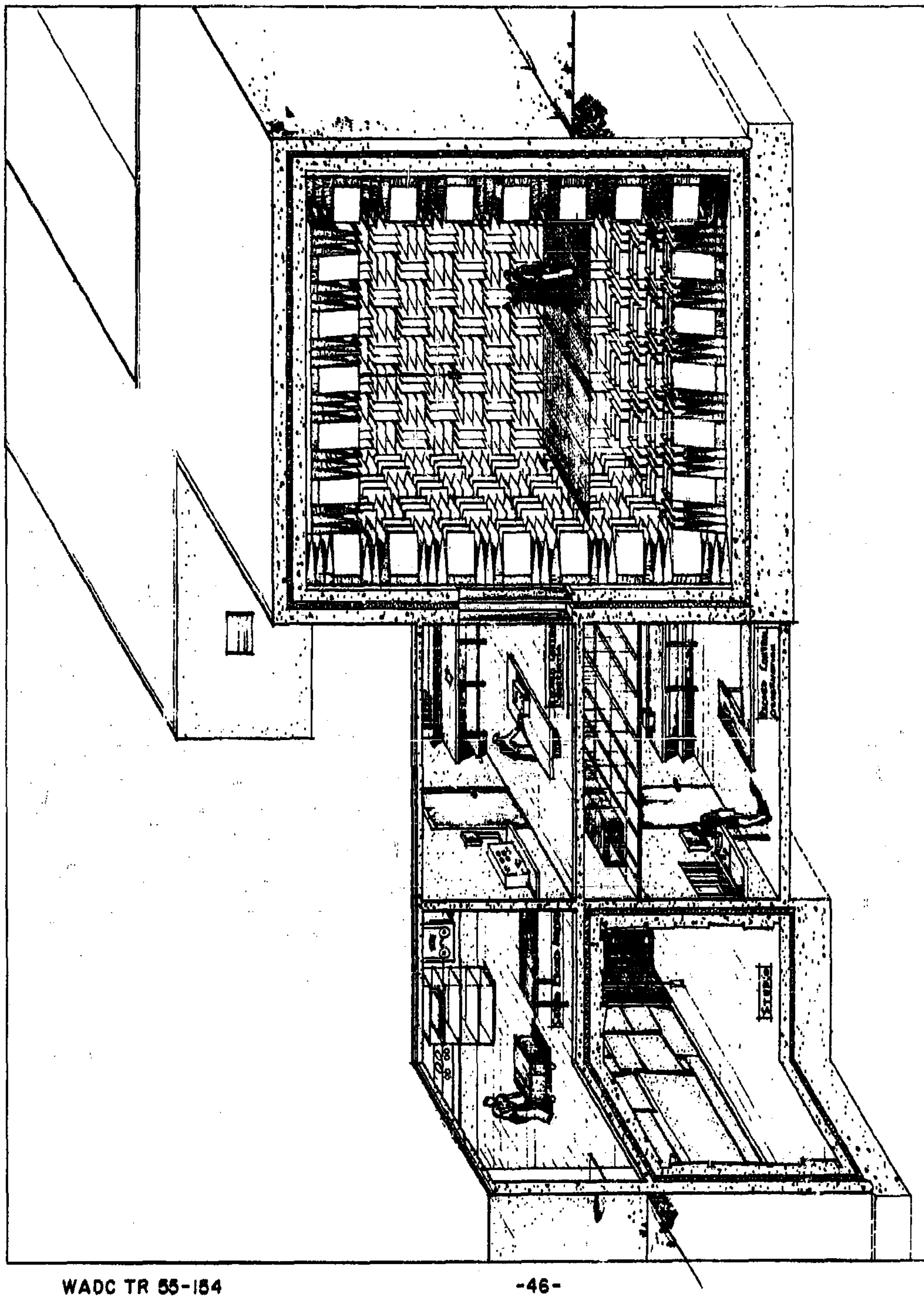
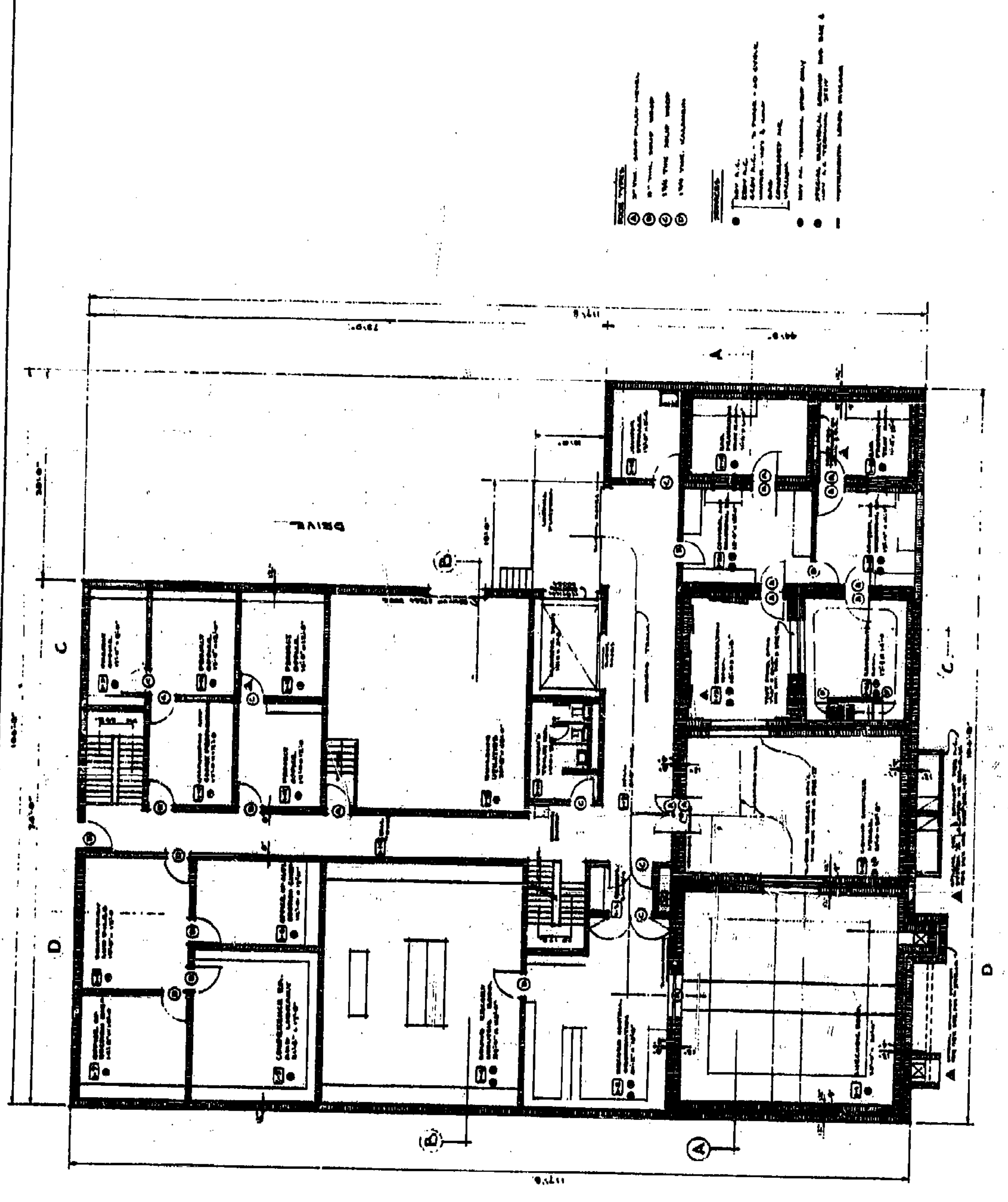
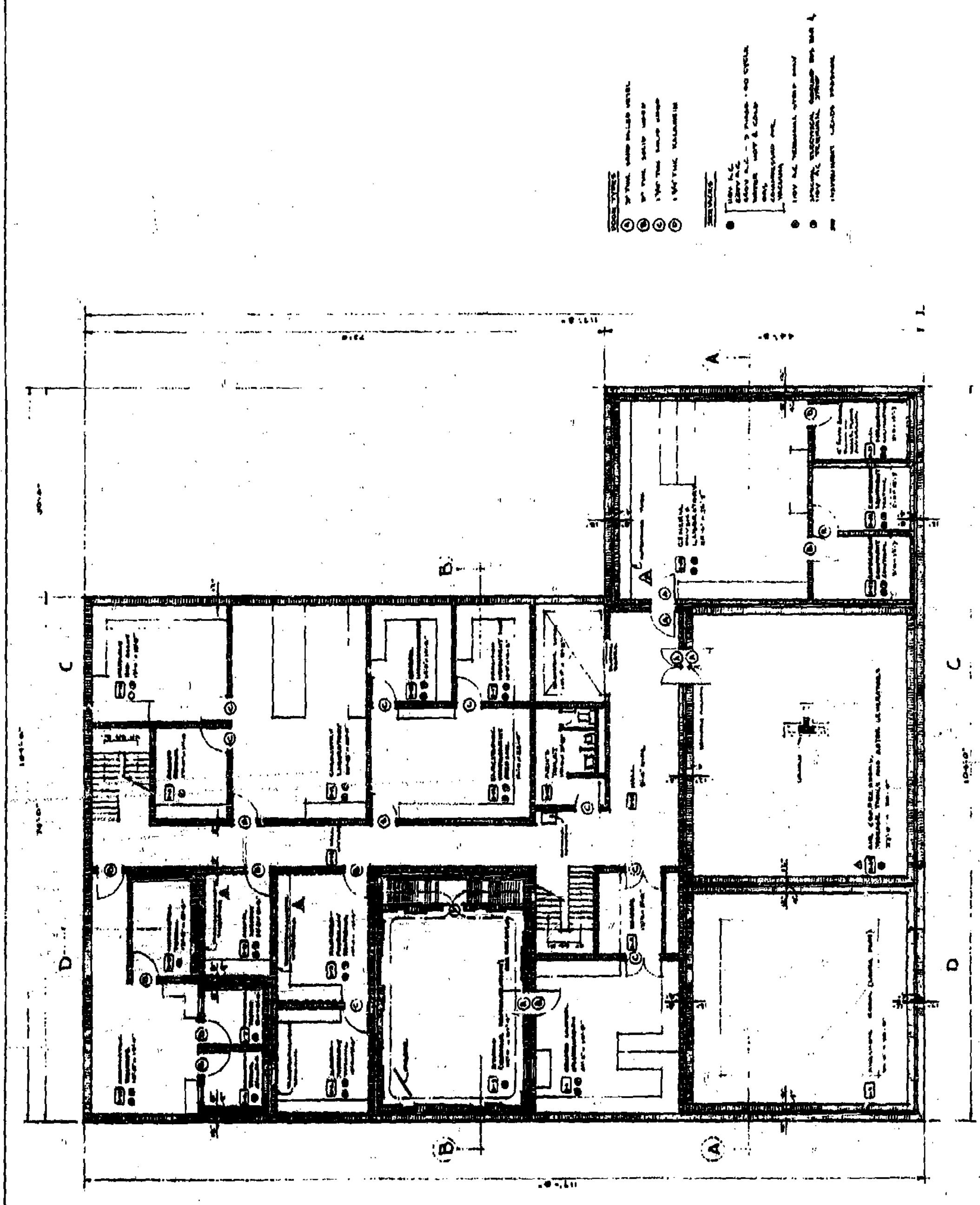


Figure A-2 Cutaway Isometric



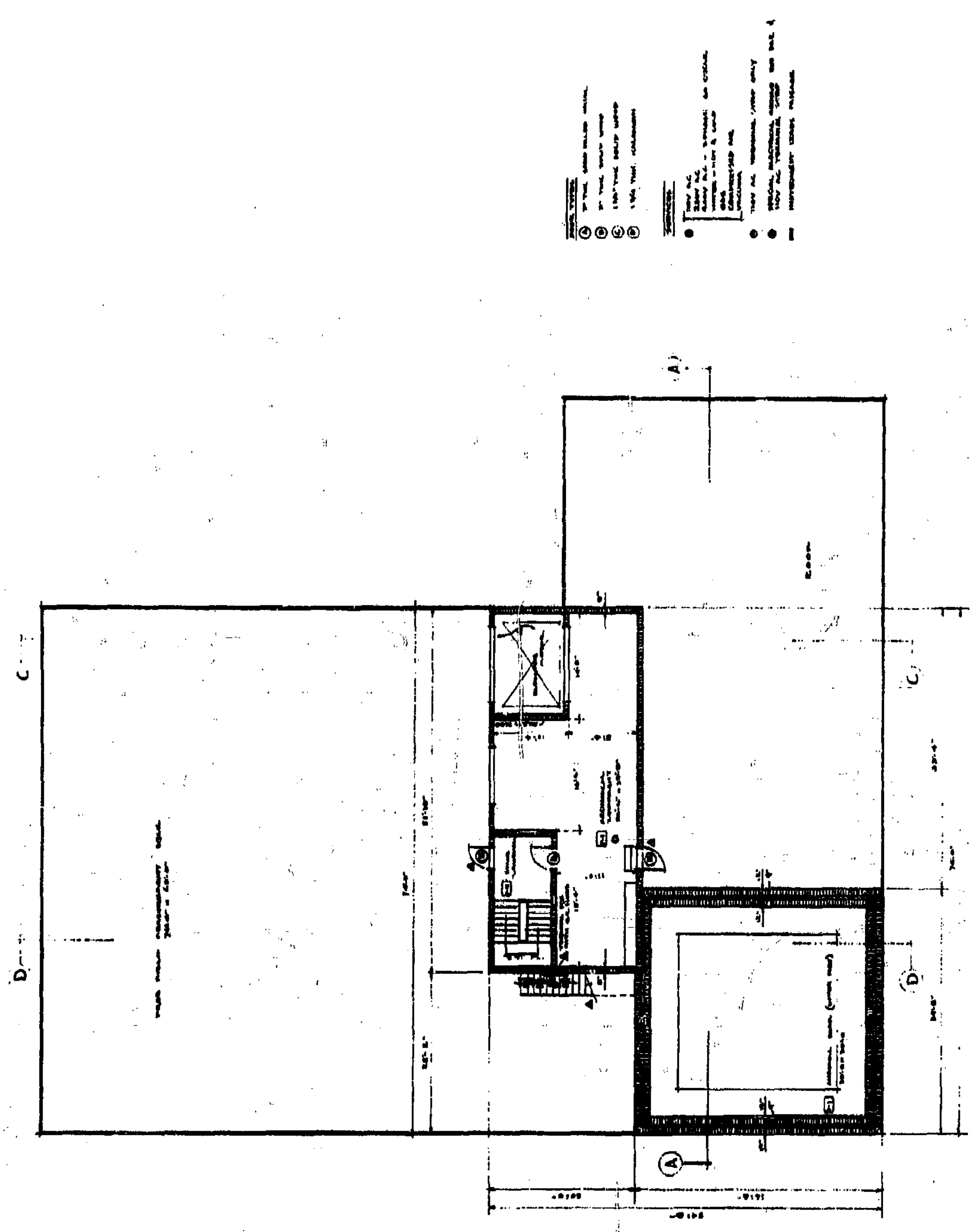
FIRST FLOOR PLAN

FIGURE A-3



BASEMENT PLAN

FIGURE A-4



PENT HOUSE & ROOF PLAN

FIGURE A-5

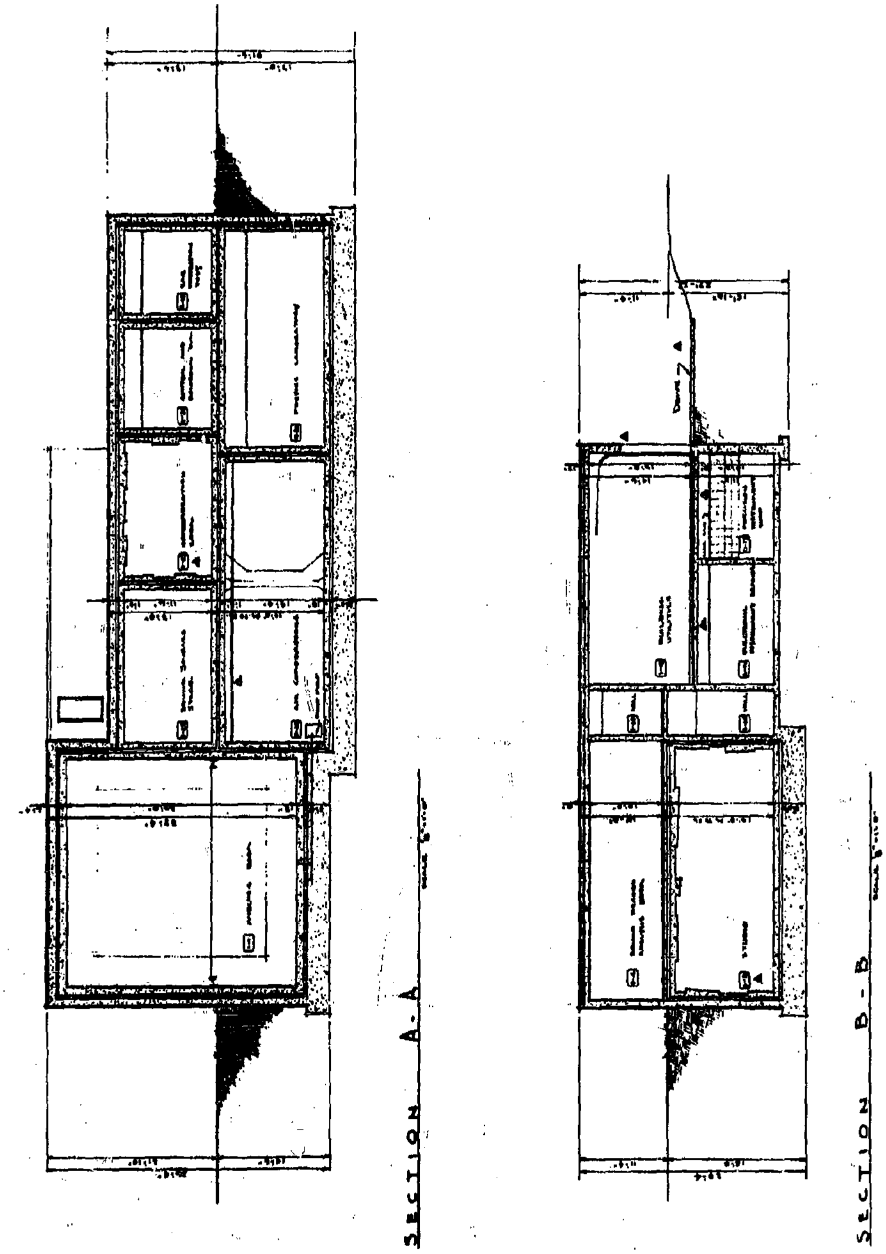


FIGURE A-6

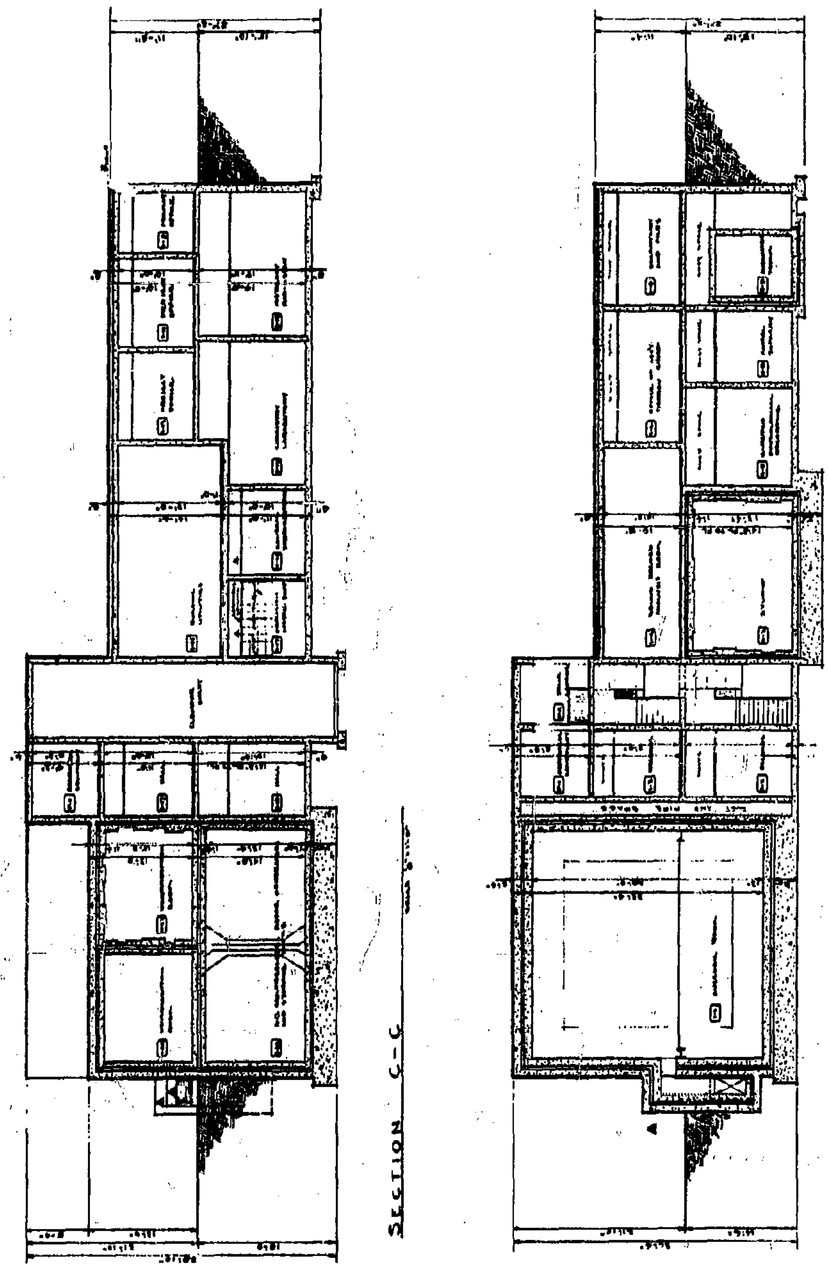


FIGURE A-7

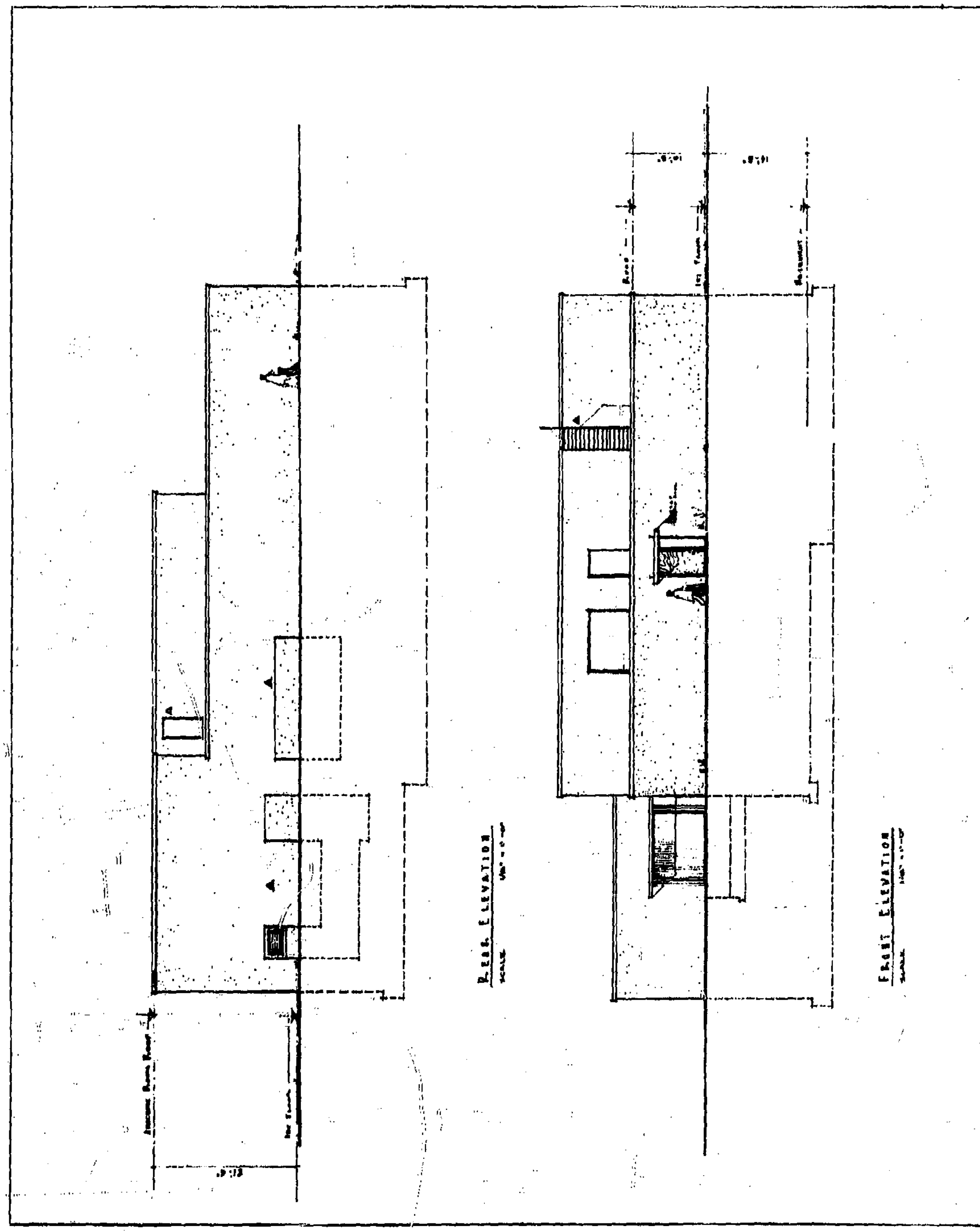


FIGURE A-8

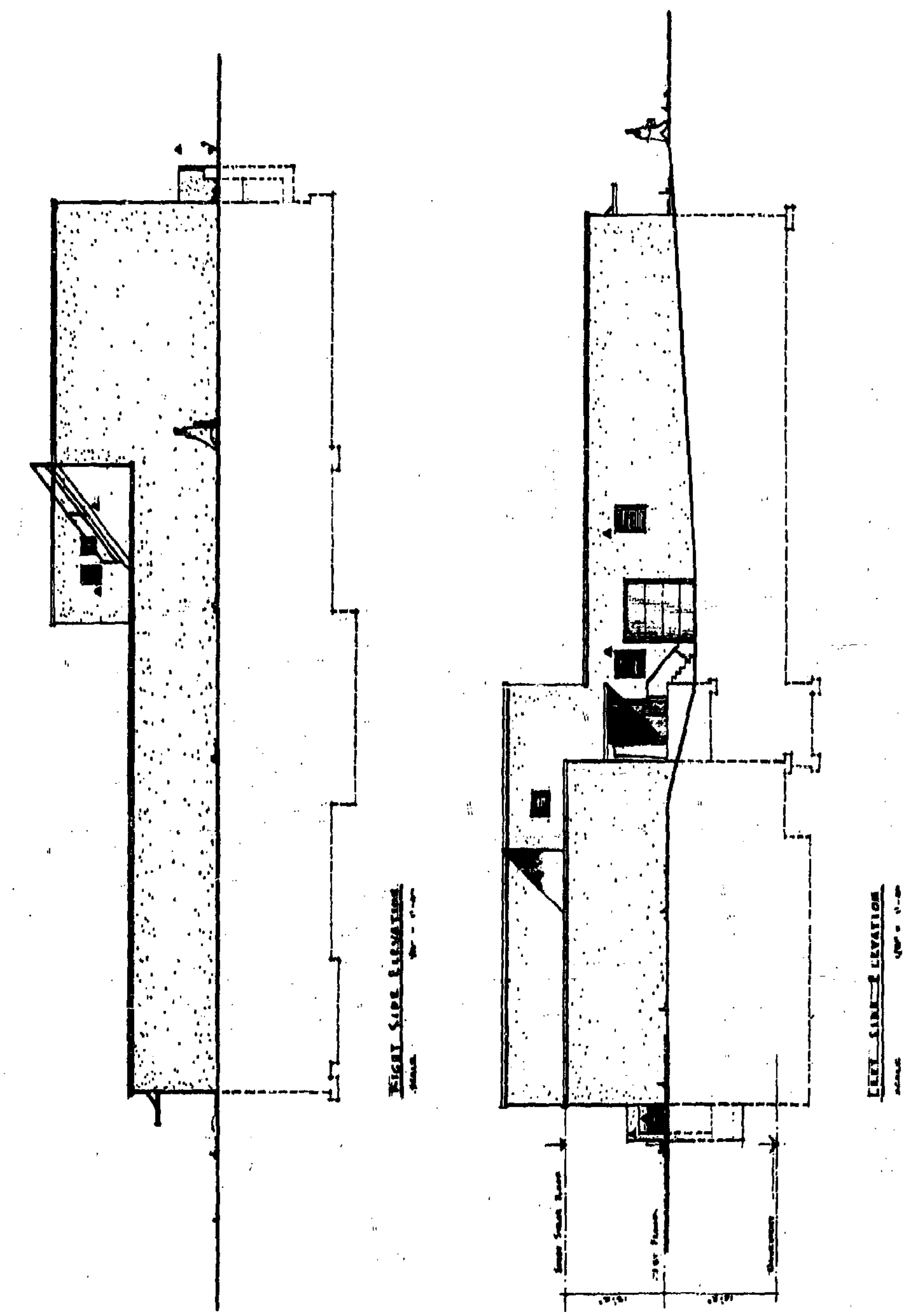


FIGURE A-9

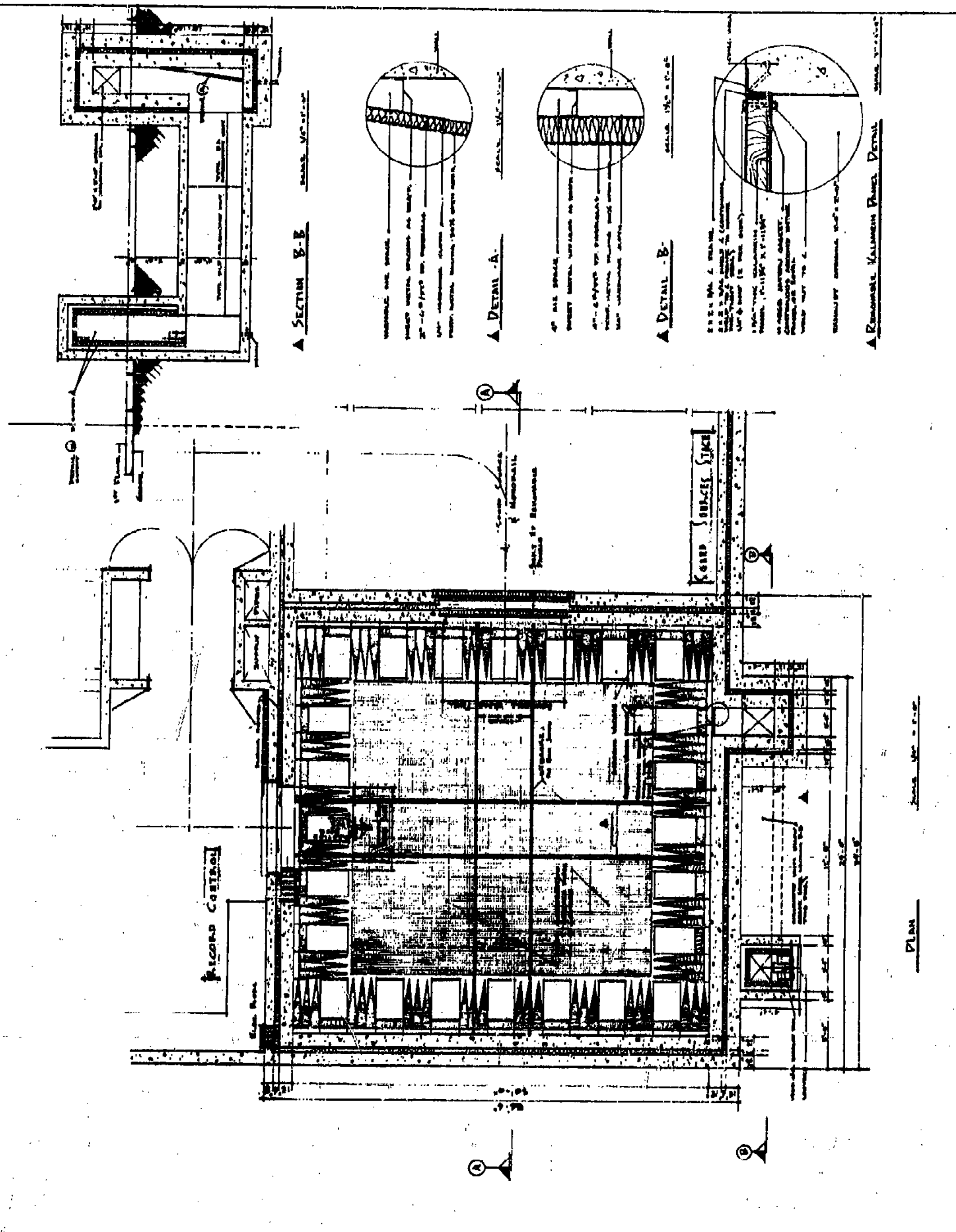
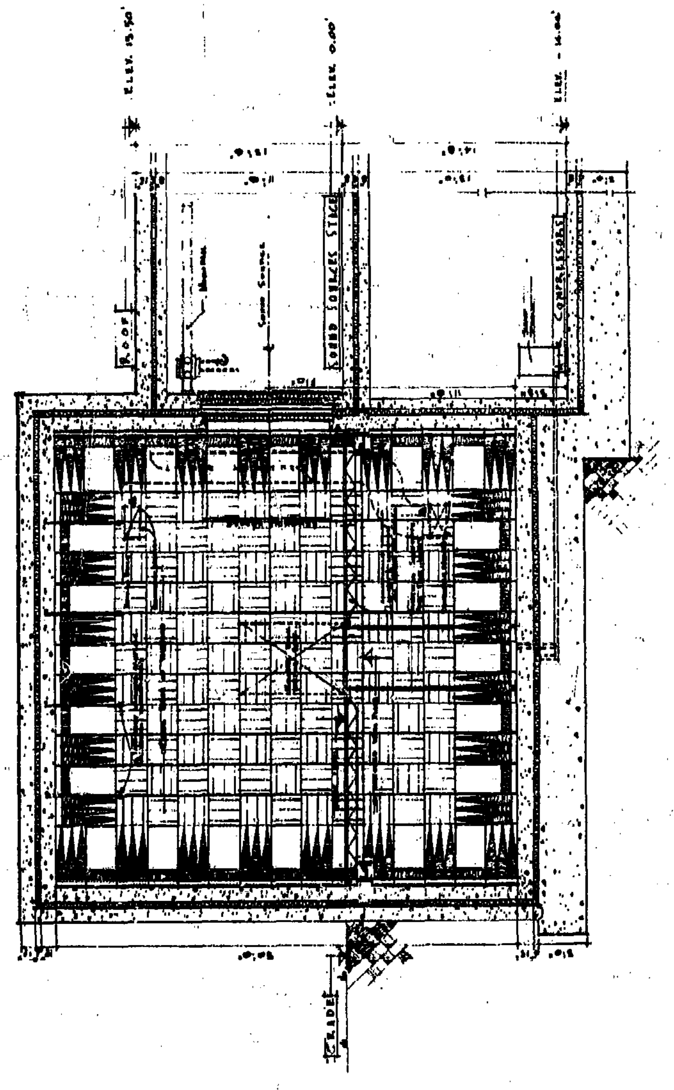


FIGURE A-10

Anechoic Room Plan



Anechoic Room Section

FIGURE A-11

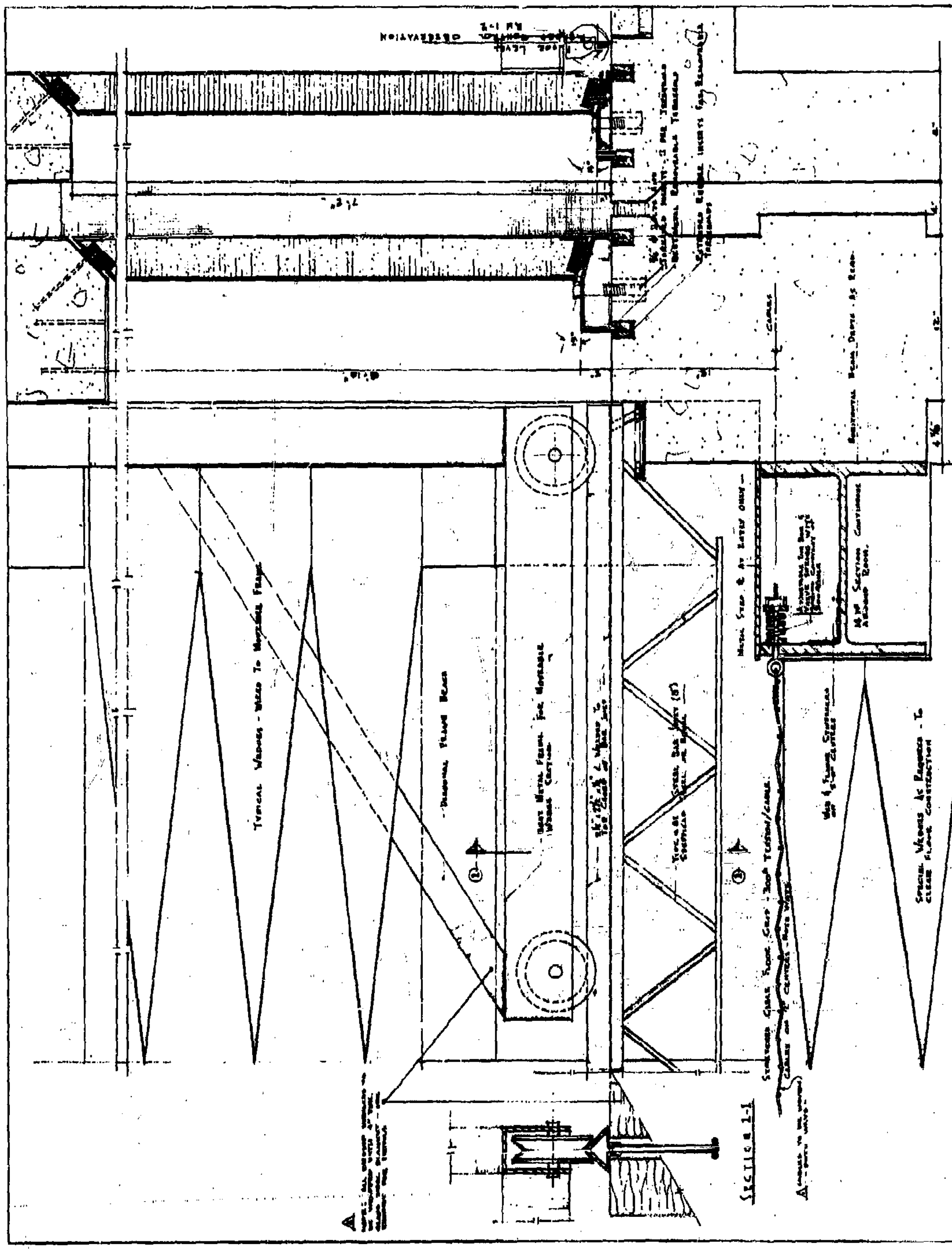
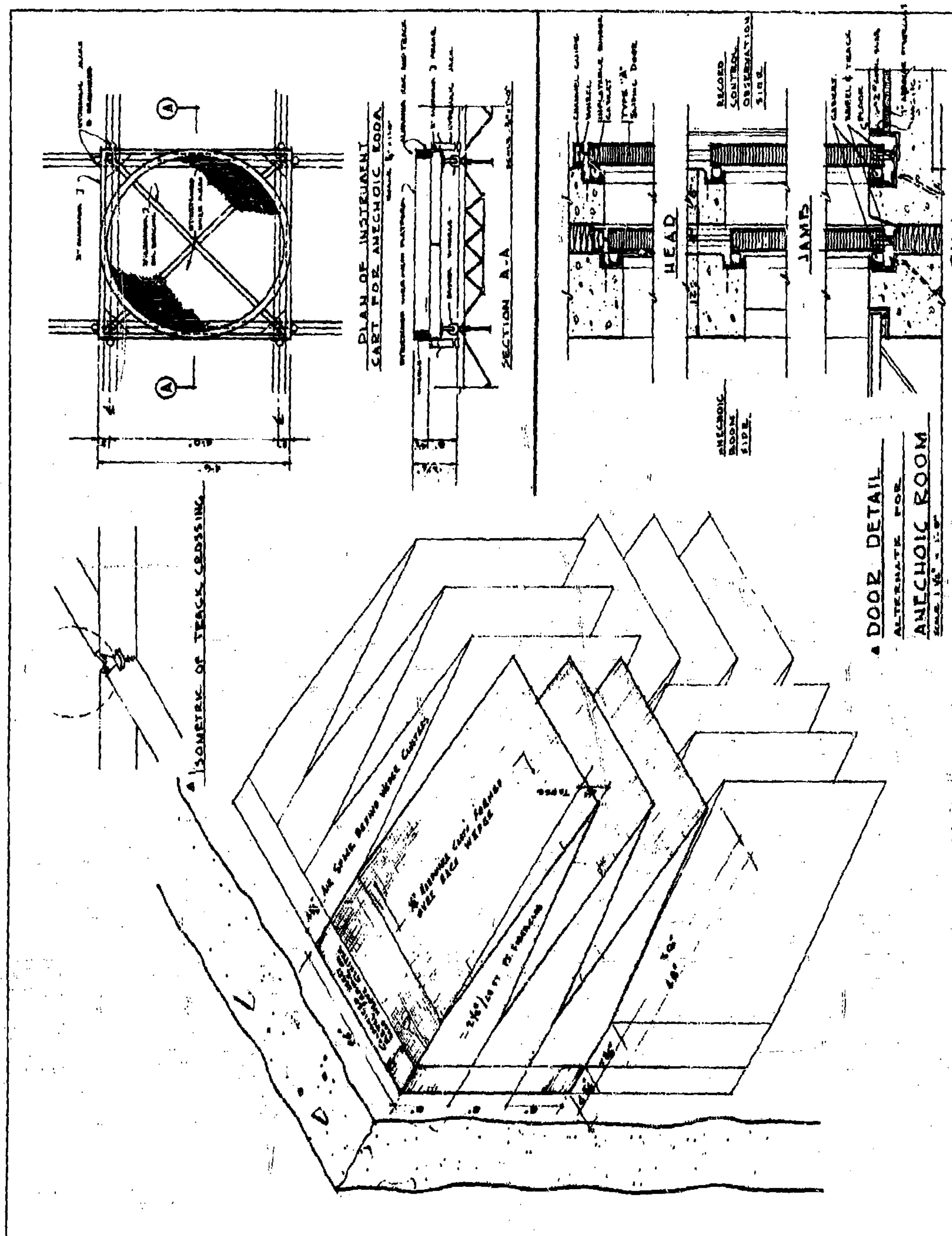


FIGURE A-12

Anechoic Room Details



ANECHOIC ROOM WEDGE ISOMETRIC

FIGURE A-13

Anechoic Room Details

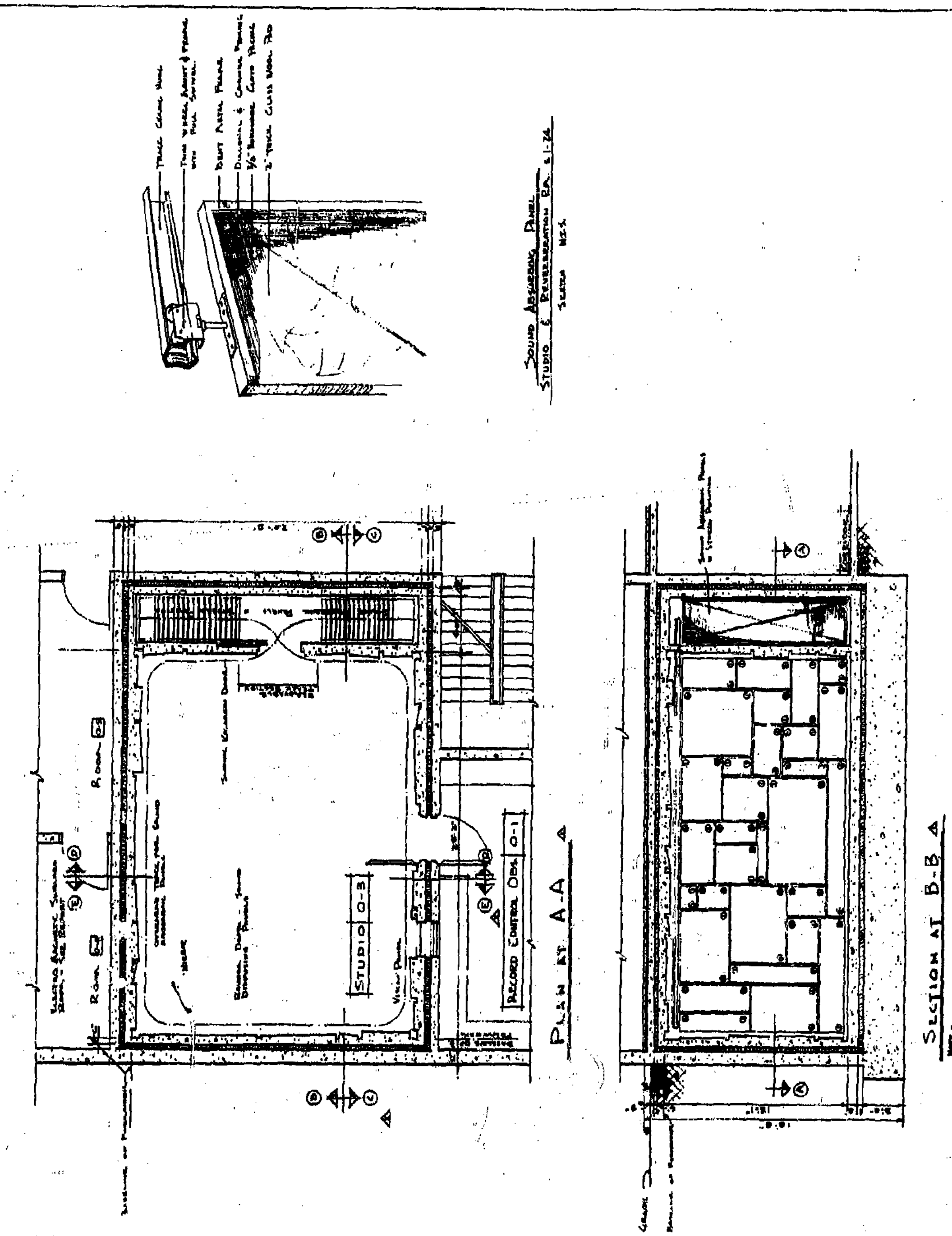


FIGURE A-14

Studio Details

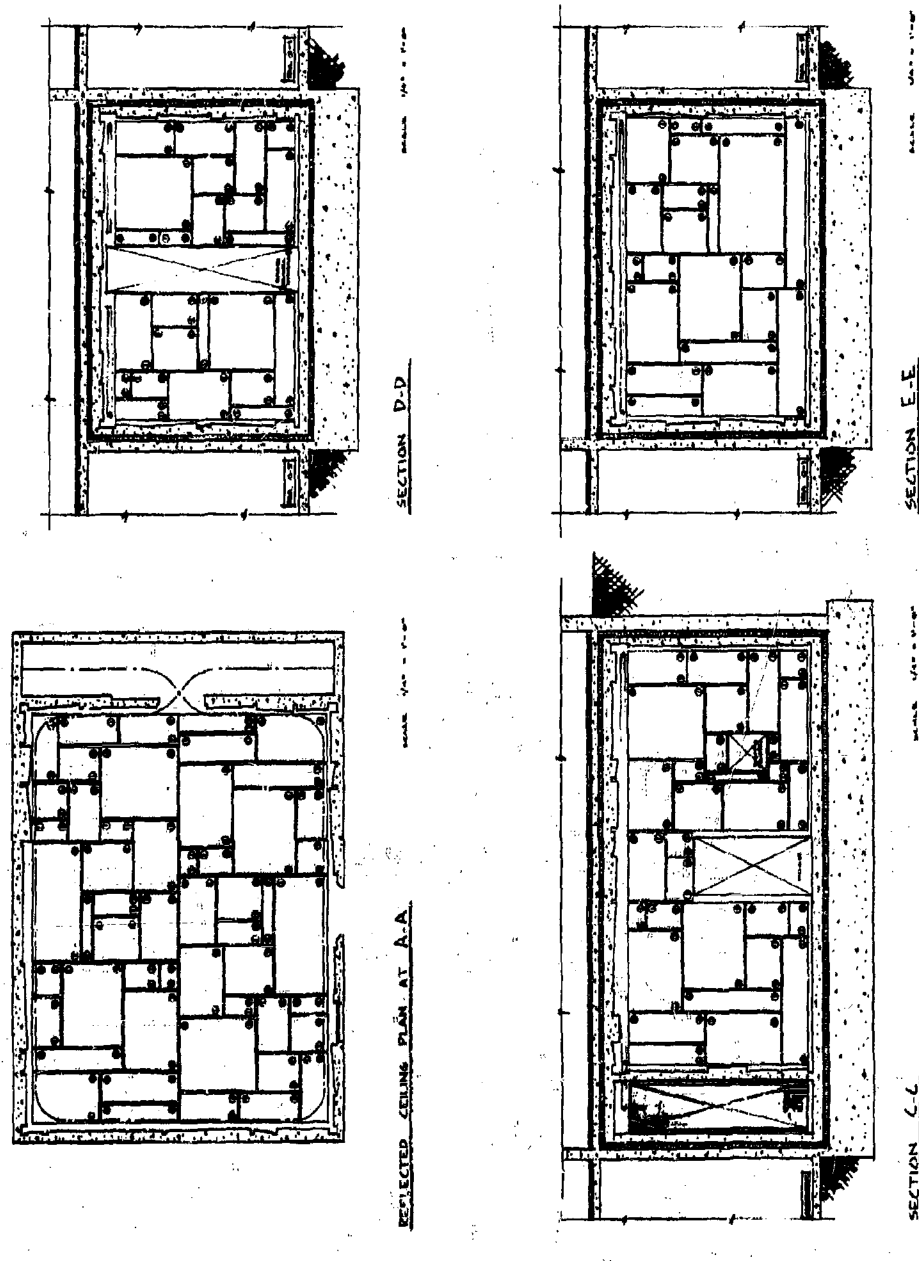
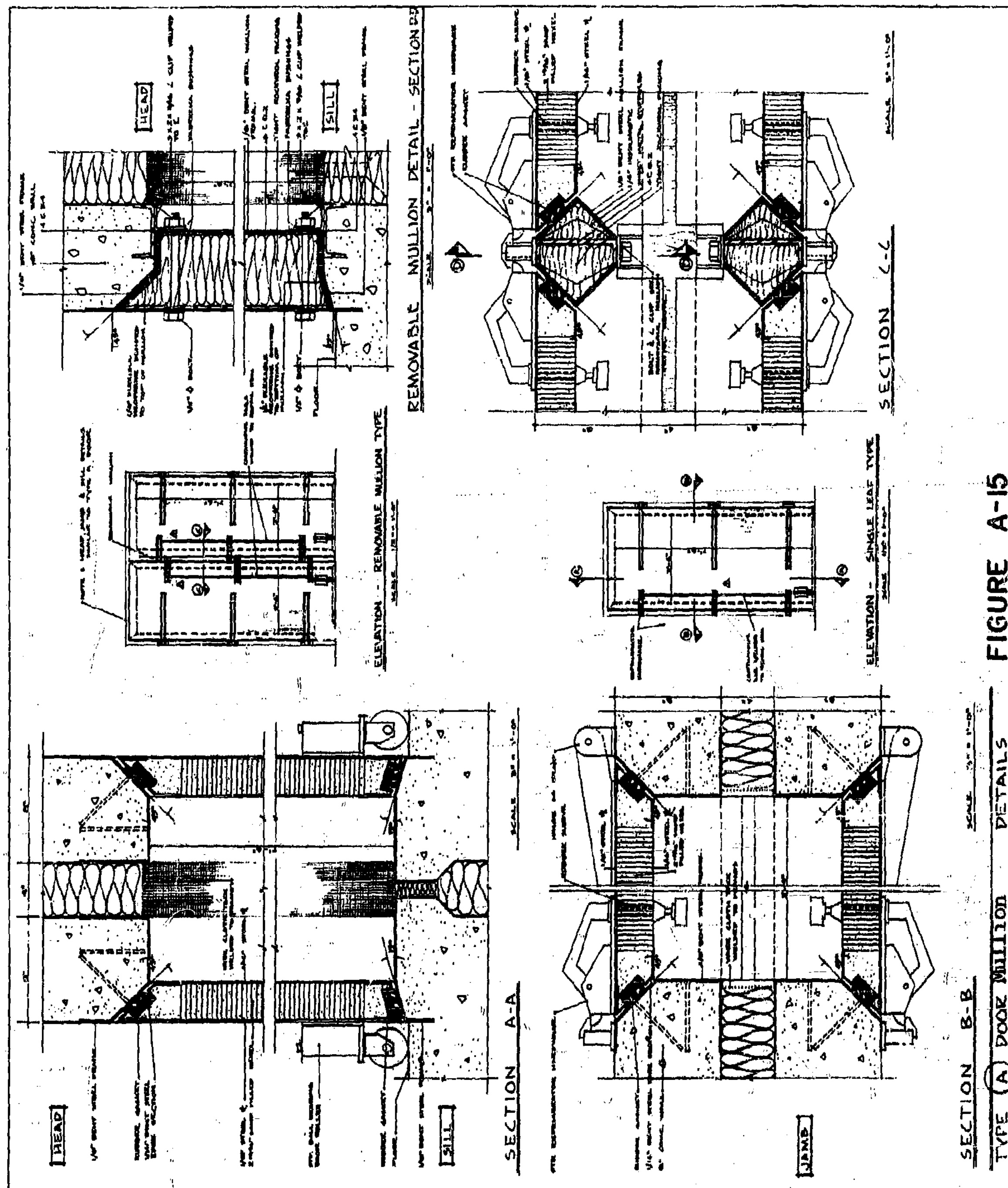


FIGURE A-14A

Studio Details



TYPE (A) DOOR Mullion DETAILS

FIGURE A-15

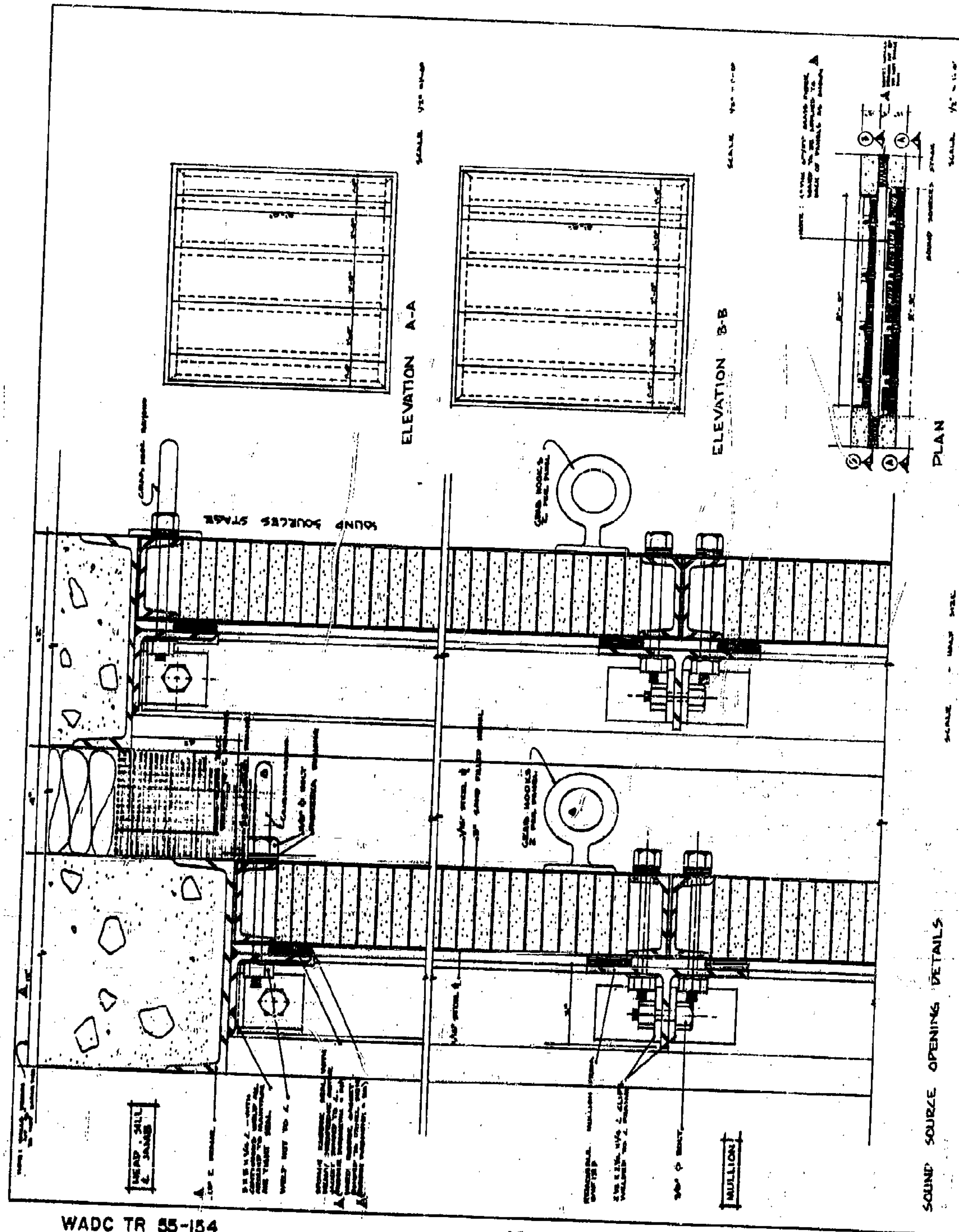
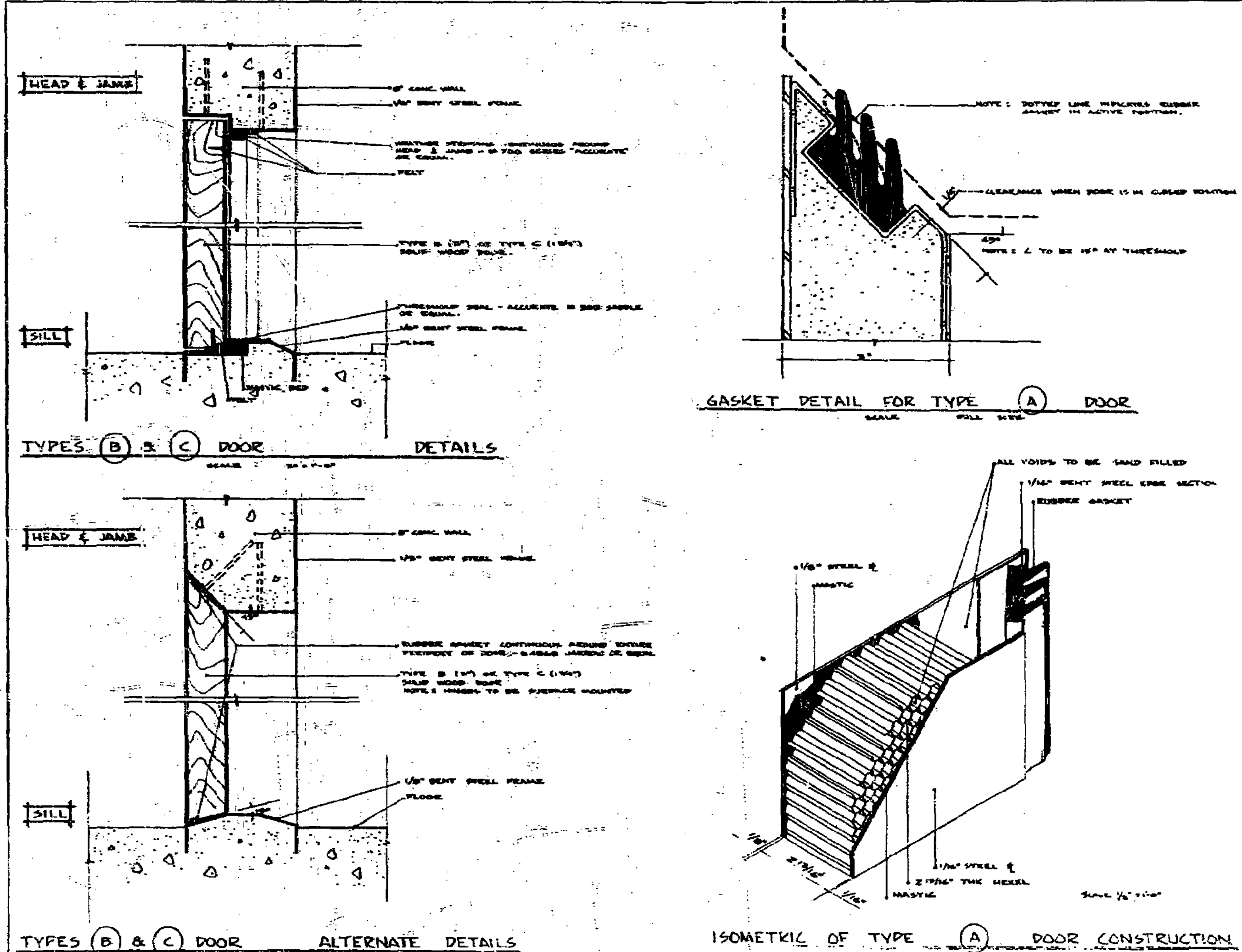


FIGURE A-17

Removable Sound Source Panel Details



Door and Gasket Details

FIGURE A-16

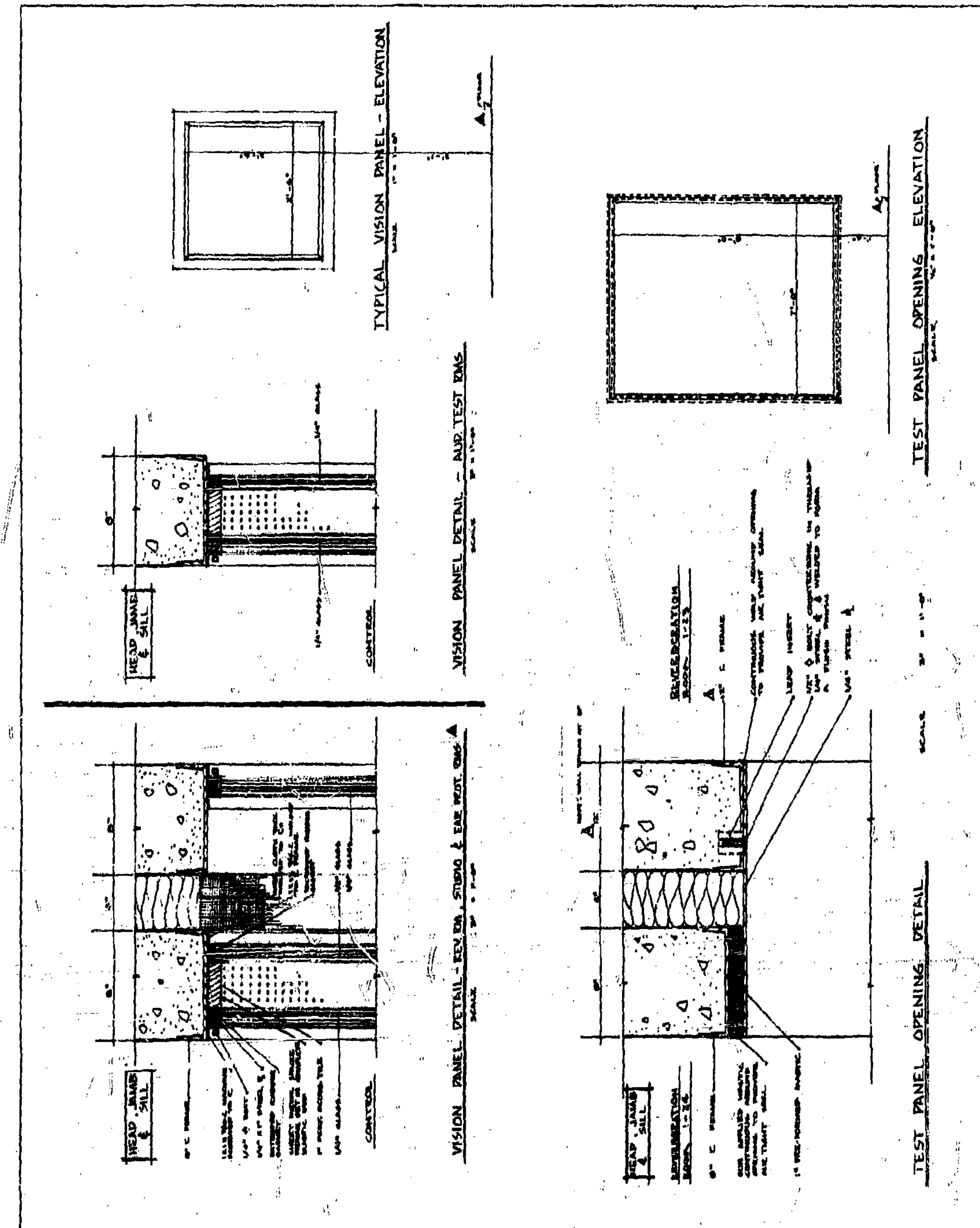
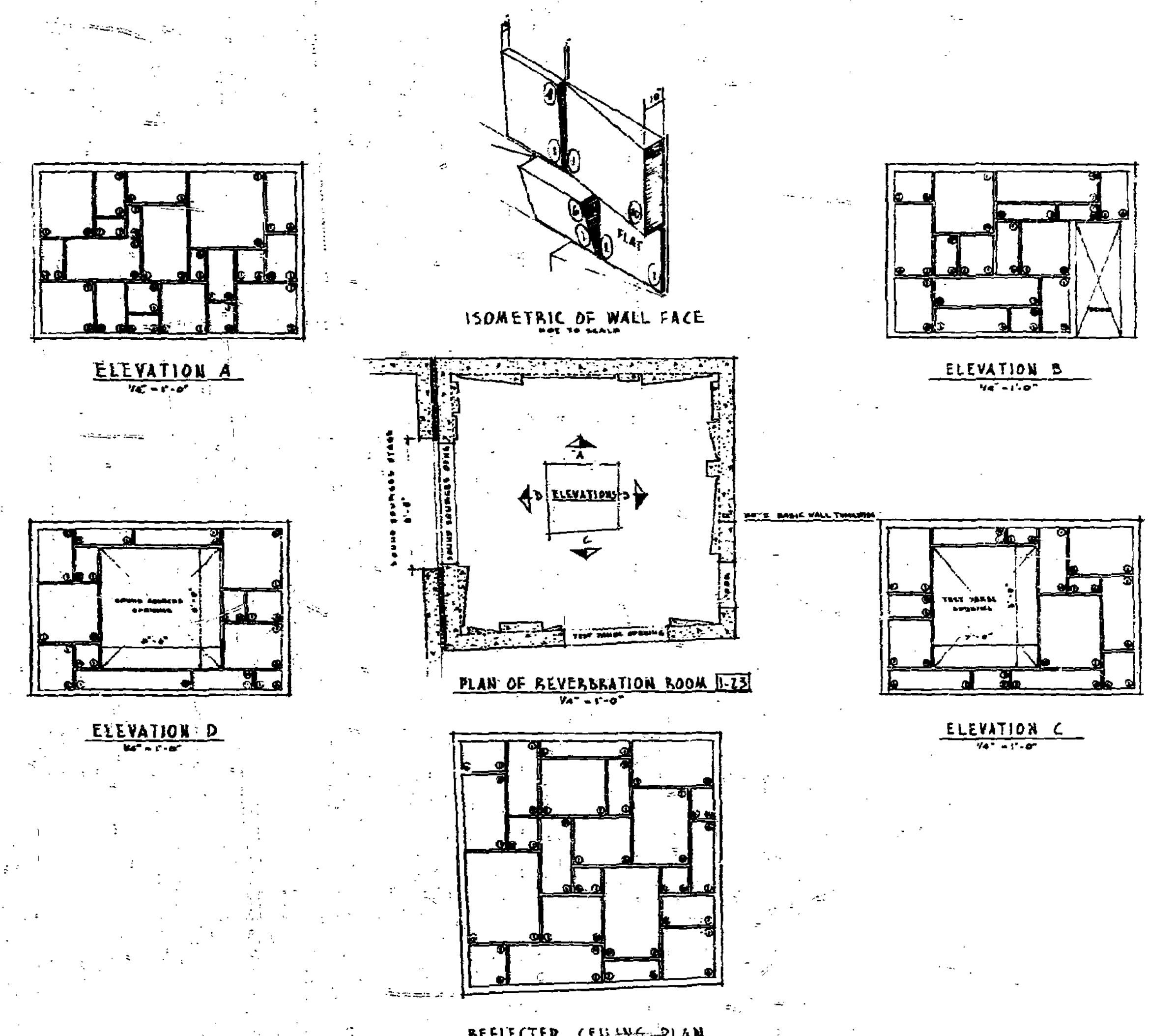


FIGURE A-18

Reverberation Room Details



Reverberation Room Details

FIGURE A-18A

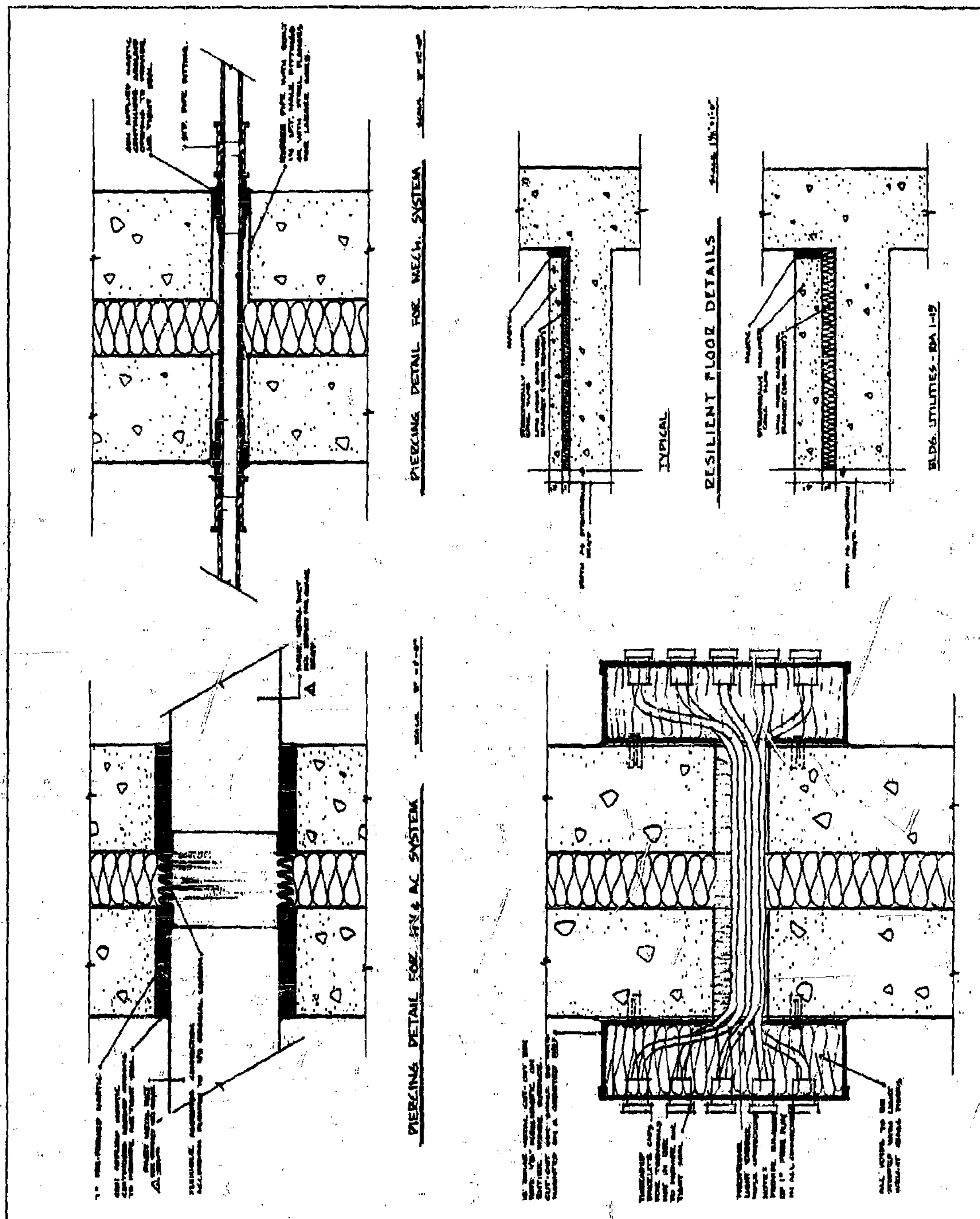
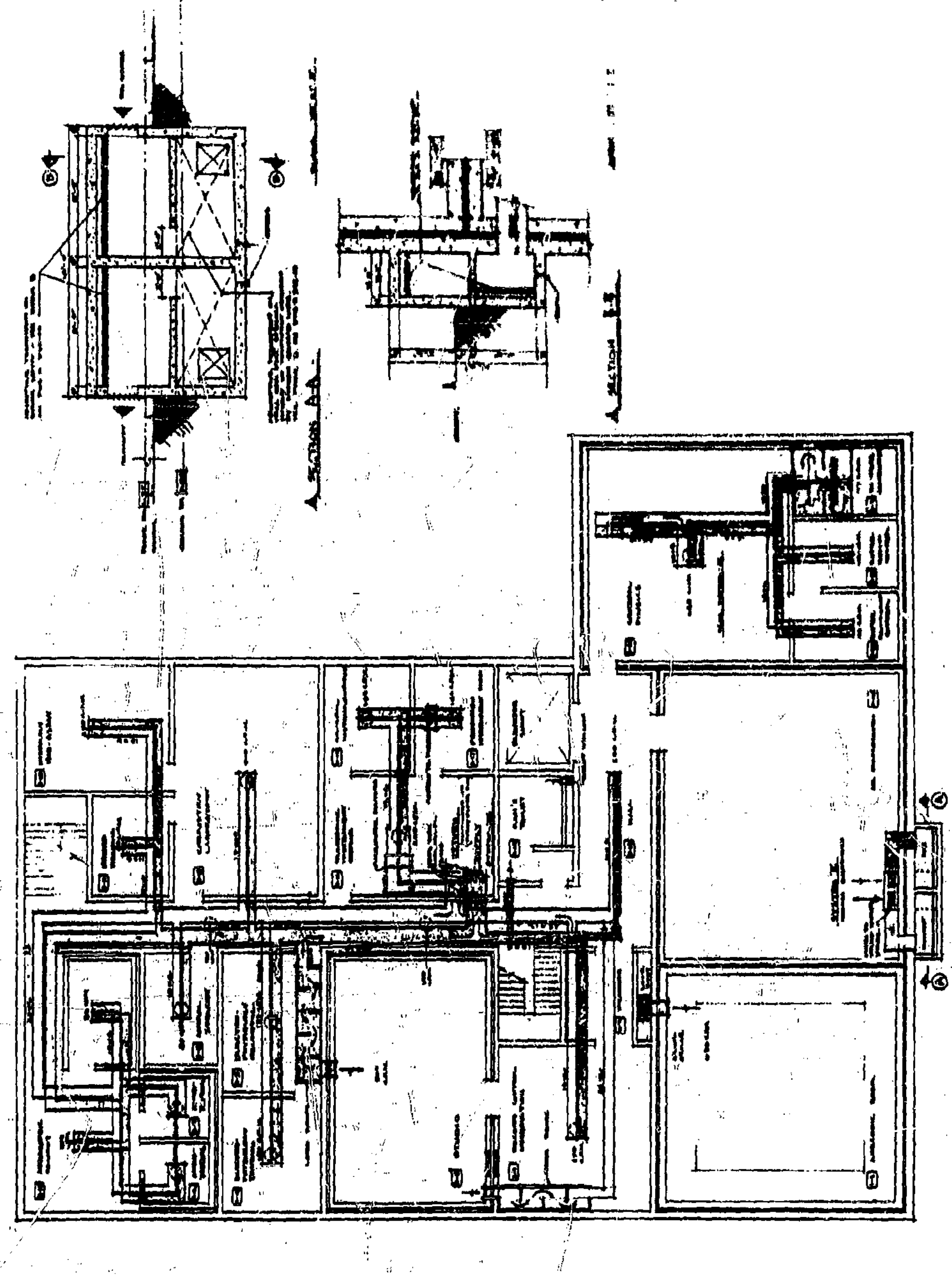
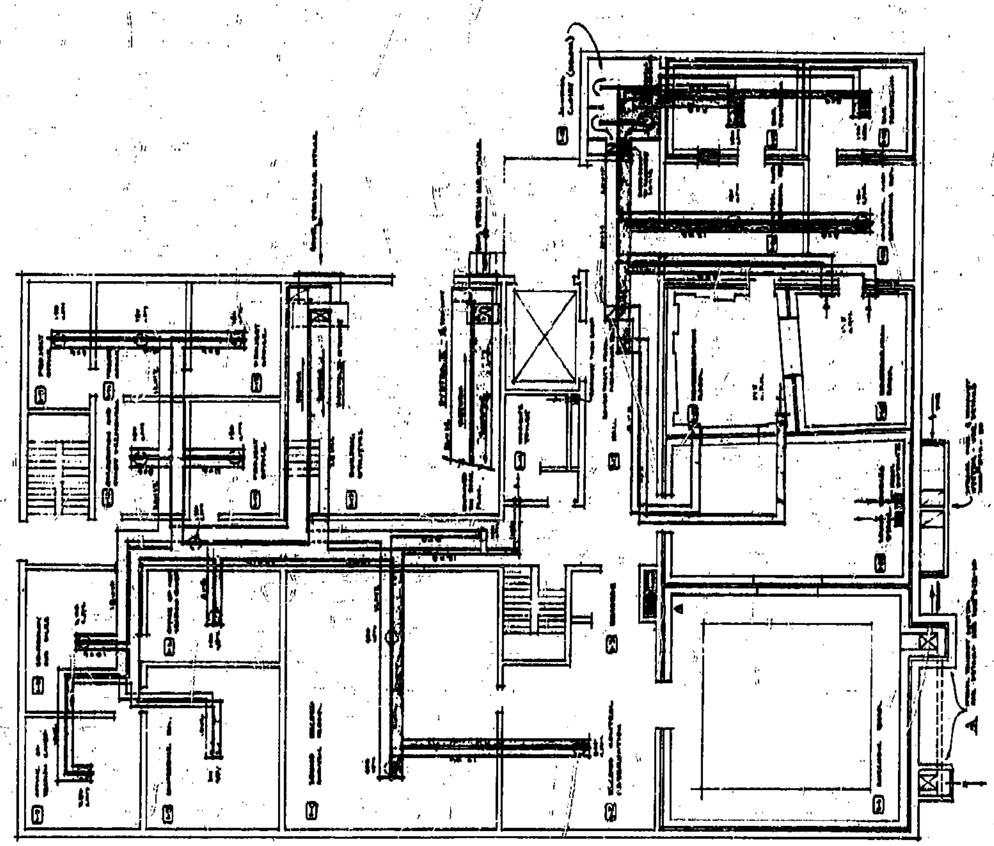


FIGURE A-19
Floor and Wall Piercing Details



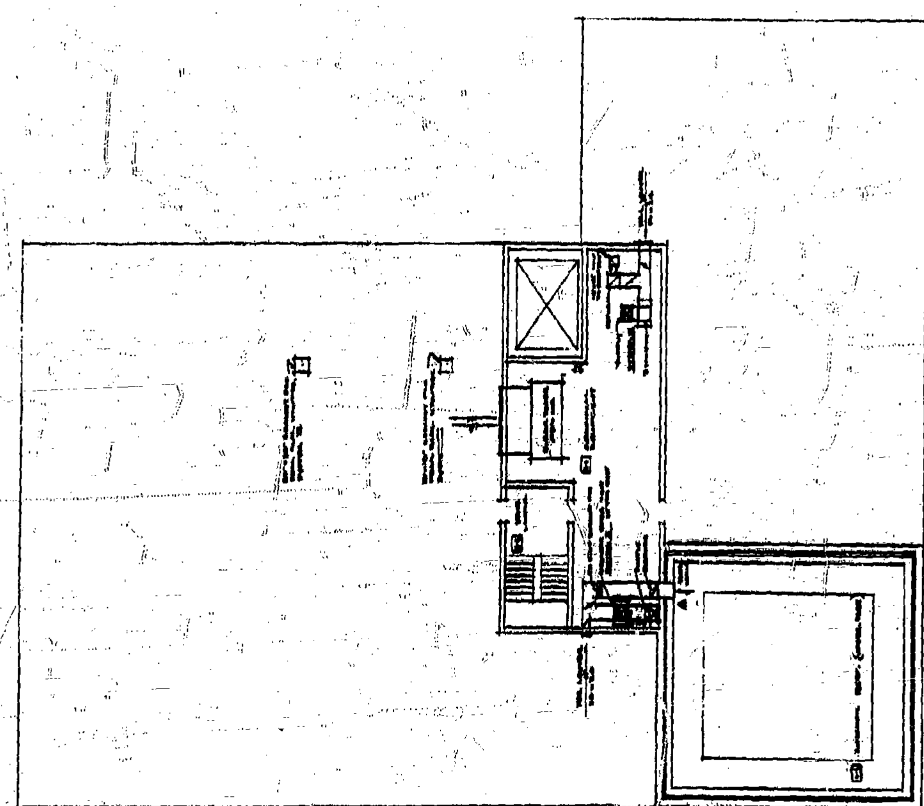
BASEMENT AIR CONDITIONING LAYOUT

FIGURE A-20



FIRST FLOOR AIR CONDITIONING LAYOUT

FIGURE A-21



PENT HOUSE AIR CONDITIONING LAYOUT

FIGURE A-22

REFERENCES

1. WADC TR 52-204, Vol. II "Handbook of Acoustic Noise Control - Noise and Man", p. 17.

2. Ref. 1, p 46.

3. H. Fletcher and W. A. Munson, "Relation Between Loudness and Masking", J. Acous. Soc. Am. 9, 1-10 (1937).

4. L. L. Beranek, ACOUSTICS (McGraw-Hill Book Company, Inc., New York, 1954), p. 328.

5. L. L. Beranek and H. P. Sleeper, Jr., "Design and Construction of Anechoic Sound Chambers", J. Acous. Soc. Am. 18, 140-150 (1946).

6. R. H. Bolt, "Note on Normal Frequency Statistics for Rectangular Rooms," J. Acous. Soc. Am. 18, 130-133 (1946).

7. V. O. Knudsen and C. M. Harris, ACOUSTICAL DESIGNING IN ARCHITECTURE (J. Wiley and Sons, Inc., New York, 1950), p. 159.

8. Ref. 1, p. 200.

9. A. London, "Methods for Determining Sound Transmission Loss in the Field", Jour. of Research, National Bureau of Standards, 26, 419-453 (1941).